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October 1, 2012

Ms. Jocelyn Boyd
Chief Clerk
Public Service Commission of South Carolina
Post Office Drawer 11649
Columbia, South Carolina 29211

RE: **Docket No. 2008-251-E and Docket No. 2012-93-E**

Dear Mrs. Boyd:

Robert P. Evans is a Progress Energy Carolinas, Inc.'s ("PEC") employee. In his prefiled testimony associated with the 2012 Application of PEC for Approval of Its Demand-Side Management ("DSM") and Energy Efficiency ("EE") Rider, Mr. Evans stated PEC would file with the Commission the final Evaluation Measurement and Verification Report for the company's EnergyWise Residential Service Load Control Program when it became available. Docket No. 2012-93-E; Evans prefiled testimony at 6. The report, which summarizes the results of the Summer 2011 and Winter 2011/12 program period, is complete and attached hereto. The report will be used to perform the true up associated with the 2013 DSM/EE cost recovery request. The report is also being filed pursuant to the Commission's May 6, 2009 Directive in Docket No. 2008-251-E approving PEC's cost recovery mechanism

Please contact me if you have any questions.

Sincerely,

A handwritten signature in black ink that reads 'Timika Shafeek-Horton'.
Timika Shafeek-Horton

cc: Courtney Edwards
John Flitter

**EM&V Report for the
EnergyWise Home Program
Summer 2011 and Winter 2011-12**

Presented to:
Progress Energy Carolinas

Prepared by:
Navigant Consulting, Inc.

September 28, 2012





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Executive Summary

The EnergyWise Home ("EnergyWise") demand response program offers Progress Energy Carolinas (PEC) residential customers the opportunity to earn credit on their electricity bill by allowing PEC to remotely control air conditioners (A/C) in the summer months and space- and water-heating equipment in winter during times of seasonal peak consumption. This report covers evaluation, measurement, and verification (EM&V) activities for the summer of 2011 and the winter of 2011-12. At the time of the final summer event of 2011, nearly 65,000 households were participating in the A/C curtailment component, and at the time of the final winter event nearly 4,500 households were participating via electric water heaters and heat pump auxiliary heat strips.

Average summer load impacts ranged from approximately 0.8 kW to 1.3 kW per participating household, depending on the A/C cycling strategy employed. In winter, average impacts were approximately 0.4 kW for water heaters and 0.6 kW for auxiliary heat strips. The average per household impact across all curtailment events by device type and cycling strategy is presented in Table 1, below.

Table 1: Summary of Average Estimated Impacts per Household

Season	Device Curtailed	Cycling Strategy	Average DR Impact (kW)	Average Demand Reduction			
				0.0	0.5 (kW)	1.0	1.5
Summer 2011	Air Conditioner	50%	0.78				
	Air Conditioner	65%	0.84				
	Air Conditioner	75%	0.86				
	Air Conditioner	100%	1.28				
Winter 2012	Heat Pump Auxiliary Heat Strips (1)	100%	0.61				
	Electric Water Heater	100%	0.42				

(1) The relatively low average per household impact of auxiliary heat strip curtailment is due to: a) the very high rate of devices not responding to the PEC control signal and b) the fact that the average includes one event with very low impacts due to relatively warm outdoor temperatures (42F on average during the event).

Source: Navigant Logger Data and Analysis

ES 1. Evaluation Methods

The evaluation is comprised of four distinct but inter-related components applied to both the winter and the summer programs:

1. **Demand Impact Evaluation** – the estimation of historic summer 2011 and winter 2011-12 curtailment impacts and the forecast of curtailment capability under different conditions,

including alternative weather conditions and times of day. Impacts were estimated using device-specific logger data and an econometric technique known as fixed effects regression modeling, the industry standard for DR program evaluations.

2. **Device Responsiveness Analysis** – the estimation of the percentage of devices that did not respond or only partially responded to PEC’s control signal. For A/C devices, estimation of the rate of responsiveness was accomplished through a comparison of logged demand immediately prior to the beginning of the curtailment period and logged demand shortly after the start of the curtailment period. For auxiliary heat strips a member of the evaluation team examined data plots of individual device/event day pairs and assigned each one to a responsiveness category based on a decision tree.
3. **Indoor Temperature Impact Evaluation** – the evaluation of the average impact that curtailment had on indoor temperatures and, for the summer, an analysis of the principal drivers of indoor temperature change. Analysis of the principal drivers of summer indoor temperature change used basic regression techniques and the overall evaluation of the distribution of indoor temperature for both winter and summer changes made use of summary statistics based on indoor temperature data recorded by loggers.
4. **Participant Perception Evaluation** – an analysis of four surveys of EnergyWise participants put into the field shortly after August curtailment events and two surveys of participants put into the field shortly after the February and March curtailment events. In some cases participants were surveyed about a “placebo” event. That is, responding participants were told an event had been called when in fact one had not, and then asked about their comfort levels during the (non-existent) event. This analysis makes use principally of cross-tabulations and summary statistics obtained from the summary data.

ES 2. Load Reduction Impacts

Summer Impacts

The principal EM&V findings regarding summer event demand impacts are as follows:

- **The estimated impacts of 0.78 kW for 50% events and 1.28 kW for the 100% event are at the expected level for residential A/C direct load control programs, given the temperature observed at the time of the events.** The forecast capability of the program is also at the expected level. At a common temperature of 90 degrees Fahrenheit, the 50%, 65%, 75% and 100% cycling strategies would have a forecast capability of approximately 0.6 kW, 0.8 kW, 1 kW, and 1.3 kW of demand reduction per home, respectively. At 100 degrees the average demand reductions would expected to be approximately: 0.95 kW, 1.2 kW, 1.5 kW and 1.9 kW for each of the four cycling strategies.
- **Impacts are approximately proportionate to the cycling strategy used, when adjusted for temperature.** That is, all else equal, a 100% cycling strategy will yield roughly twice the demand impact of a 50% cycling strategy and a 75% cycling strategy will yield roughly one and a half times the demand impact of a 50% cycling strategy.

- **Snapback demand impacts sometimes last more than four hours following the event, with the increase in demand in any given hour being approximately 25% - 50% as large as the average estimated demand reduction during the period of the event.** The magnitude of snapback appears to be affected more by the length of the curtailment than the cycling strategy used. The two single hour events both had the smallest indoor temperature rise of all events, resulting, in the case of the 100% cycling event, in a snapback lower than that of the average 50% cycling event in the period immediately following the curtailment event.
- **In aggregate across all events in the summer of 2011, the program is estimated to have delivered an average of 55 MW of DR curtailments.** Should PEC apply a more aggressive cycling strategy at present levels of program participation, the program could potentially deliver over 100 MW of DR curtailment capability on days with temperatures in the high 90s.

Winter Impacts

The principal EM&V findings regarding winter event demand impacts are as follows:

- **Water heater curtailment yields a relatively predictable impact of 0.42 kW on average that is mostly insensitive to weather.** Water heater demand in the morning, likely driven by participants' morning showers, is remarkably consistent, as are the DR impacts of curtailment, regardless of weather.
- **Heat pump auxiliary heat strips yielded DR impacts of 0.75 kW per household on event days when the temperature was less than 40 degrees Fahrenheit and only 0.05 kW on the event day where the temperature was 42 degrees Fahrenheit.** These impacts are significantly lower than their potential due to a high rate of auxiliary heat strips not responding to the PEC curtailment signal. Devices that completely responded to the PEC control signal had an estimated average DR impact across all events of nearly two and a half times that reported for auxiliary heat strips in Table 1, above.
- **The magnitude of auxiliary heat strip load reductions increases at an increasing rate as the temperature falls.** That is, the relationship between auxiliary heat strip demand and outdoor temperature is not linear; the DR impact of curtailing auxiliary heat strip at 20 degrees Fahrenheit will be more than twice that of curtailing auxiliary heat strip at 40 degrees Fahrenheit.
- **Snapback is much more pronounced for the winter program than for the summer, exceeding average demand reductions for a short period following each event.** The average snapback demand impact in the first hour occurring fifteen minutes after the end of the curtailment period is greater than the average DR impact realized over the curtailment event for both auxiliary heat strips and water heaters. For water heaters the average snapback demand impact in that hour can be more than twice the average DR impact realized over the curtailment event.
- **In aggregate across all events in the winter of 2011-12, the program is estimated to have delivered an average of 4 MW of DR curtailments.** Should PEC succeed in significantly improving the auxiliary heat strip response to its control signal, EnergyWise could potentially offer nearly 10 MW of winter peak DR on very cold mornings.

ES 3. Device Responsiveness

The evaluation team estimated the share of A/C units and auxiliary heat strips did not respond, or only partially responded, to PEC's control signal. Initial investigations of water heater response rates indicated that the vast majority were completely responsive to PEC's control signal, so a more in-depth analysis of response rates for water heaters was not conducted.

Summer Device Responsiveness

The most significant findings of this analysis are that:

- **On average, 11% of A/C units that were in use both prior to and following an event appear to have not responded to the PEC control signal.** This response rate was fairly consistent across events, fluctuating between 7% and 15% for any given event.
- **No device that was in use both prior to and following an event for more than three of the eleven events was assessed to have been non-responsive for every single event.** Thus, the non-responsiveness of A/C devices cannot be ascribed solely to a small number of malfunctioning switches.
- **There does not appear to be a systematic pattern of device non-responsiveness, either over time or by geographic region of PEC's territory.**

Winter Device Responsiveness

- **On average across all events, over 40% of auxiliary heat strips did not respond at all to the PEC control signal.** This non-response rate was relatively consistent, fluctuating between 35% and 45% by event.
- **On average, over 20% of auxiliary heat strips were only partially responsive to the PEC control signal when the average outdoor temperature during the event was less than 40 degrees Fahrenheit.** Given the control strategy –or complete shut off of the strips – this is puzzling; devices should either be completely responsive or completely non-responsive.
- **No obvious pattern exists indicating the possible cause of auxiliary heat strip non-response.** Only a very small number of devices in the EM&V sample were non-responsive to all events; the majority were completely responsive for at least one winter event.

ES 4. Indoor Temperature Impacts

Summer Indoor Temperatures

The principal EM&V findings with regard to summer indoor temperature data were that:

- **On average the increase in indoor temperatures during summer events was relatively small (between one and two degrees Fahrenheit).** A significant minority (over 20%) of thermostats, however, recorded changes in indoor temperature over the course of events as high as three or four degrees Fahrenheit.

- **The most significant factor impacting the change in indoor temperature during summer events over which PEC has control appears to be the length of the curtailment event.** The impact of the curtailment strategy on indoor temperature appears to be secondary to the impact of the length of the period.

Winter Indoor Temperatures

- **For completely responsive units, curtailment on the coldest morning event led to a fall in indoor temperatures across all participants studied of between just under two to nearly six degrees Fahrenheit.** The lowest temperatures recorded in households with these completely responsive units during event hours and the hour immediately following the event was between 59 and 69 degrees Fahrenheit.
- **The average change in indoor temperature is remarkably consistent from event to event, showing only modest sensitivity to outdoor temperatures.** Despite large fluctuations in outdoor temperature (between 18 and 42 degrees Fahrenheit on event days) the difference in indoor temperature for a given individual between event and non-event days is very similar from event to event.

ES 5. *Participant Perceptions*

Analysis of participant perceptions was intended to determine the degree to which participants were aware of curtailment events, and if aware, what changes participants noticed during the event, including perceptions of comfort. In some cases participants were surveyed about a “placebo” event for which responding participants were told an event had been called when in fact one had not.

Summer Survey

The principal EM&V findings from the analysis of participant perception were as follows:

- **Participants are generally unaware of curtailment events when they happen.** Most survey respondents indicated that they had not been aware that an event had occurred in the previous few days. More placebo respondents indicated that they were aware an event had occurred recently (when one hadn’t) than non-placebo respondents (who were subject to real events).
- **Only about 10% of survey respondents who had experienced a real (non-placebo) event indicated that they were “much less comfortable” than normal.** Most indicated they were “somewhat less comfortable” than normal and none indicated that they were “very uncomfortable.” Interestingly, more non-placebo respondents than placebo respondents characterized their comfort during the event as: “the same as a normal afternoon”.
- **Participants are generally satisfied with the EnergyWise program.** Over half of the respondents indicated that their experience with the program was “about what I expected” and 15% regarded the program as “better than I expected”. Only 4% indicated that their experience with the program was “worse than I expected”. Combined with PEC’s finding of an annual participant attrition rate of approximately 2%, this suggests that participants are likely to remain in the program for many years once recruited.

Winter Survey

- **Most participants are unaware of curtailment events when they occur.** 95% of survey respondents indicated that they were not aware that a curtailment event had occurred in the previous few days.
- **Very few participants that were exposed to an actual curtailment event noticed changes in indoor air temperature and comfort level, or water temperature.** In fact, the same number of placebo respondents noticed a “change” as did non-placebo respondents.
- **Participants are generally satisfied with the EnergyWise program.** Over a quarter of all respondents indicated that their experience with the program was “better than expected” and only 1% indicated that their experience with the program was “worse than I expected” with the balance of respondents unsure or indicating that their experience with the program was “about what I expected”.

ES 6. Recommendations

The EM&V team recommends the following actions to improve program performance. More detailed versions of these recommendations appear in Section 5, at the conclusion of this report.

Recommendation Topic	Recommended Actions
Technical Issues	1. Consider a thorough investigation into the cause or causes of device non-responsiveness.
System Planning and DR as a System Resource	2. Use more aggressive cycling strategies in the summer to extract more value from the DR resource.
	3. Increase coordination with system planning staff to determine the optimal summer curtailment event profile and test that profile.
	4. Consider the impact of winter snapback when recruiting program participants.
Participant Recruitment and Retention	5. Continue its practice of not advertising when curtailment events take place.

1. Introduction

The EnergyWise Home (“EnergyWise”) demand response program offers Progress Energy Carolinas (PEC) residential customers the opportunity to earn credit on their electricity bill by allowing PEC to remotely control air conditioners (A/C) in the summer months and space- and water-heating equipment in winter during times of seasonal peak consumption. This report covers evaluation, measurement, and verification (EM&V) activities for the summer of 2011 and the winter of 2011-12.

EM&V is a term adopted by PEC and refers generally to the assessment and quantification of the energy and peak demand impacts of an energy efficiency or demand response program. For DR, estimating reductions in peak demand is the primary objective, as energy impacts are generally negligible. EM&V also encompasses an evaluation of program processes and customer feedback, typically conducted through participant surveys.

1.1 Objectives of the Evaluation

This EM&V report is intended to support program improvements as well as to verify program impacts as per the requirements established by the North Carolina Utilities Commission and the Public Service Commission of South Carolina. Major objectives of the evaluation were as follows:

- » Estimate the impact of direct load control on residential demand in the summer and winter under a variety of different load control strategies.
- » Identify and document participant feedback on experience with curtailment events and the EnergyWise program as a whole.
- » Identify areas for improvement to the program and recommend related modifications that can increase participation, load reductions, and cost-effectiveness.

1.2 Program Overview

The EnergyWise program was developed in response to PEC’s determination that a curtailable load program would be a valuable resource for the company, and provide an opportunity to engage directly with customers to help reduce costly seasonal peak demand. The program seeks to attract DR resources by incenting residential customers to allow PEC to remotely control the most important drivers of summer peak demand typically found in the home – central air-conditioning. In PEC’s Western region the program attracts winter DR resources by incenting residential customers to allow PEC to remotely control electric water heaters and heat pump auxiliary heat strips.

The program offers an annual bill credit of \$25 to customers that choose to allow PEC to control their central air-conditioner. In PEC’s Western region participants are also offered an additional \$25 per year per device to allow PEC to control participants’ water heaters and/or auxiliary heat strips.

Eligibility. In order to be eligible to participate in the EnergyWise program, a household must meet the following criteria:

- For A/C participants: the participant’s air-conditioner must be a central unit with a ducted system. Wall, window and ductless units are not eligible for participation.

- All central A/C units in the home must be controlled by PEC as part of the EnergyWise program.
- Participants must both own and occupy the residence at which the controls are installed¹.
- Residential electricity service must be in the name of the participant.

Participation in the winter water heater and auxiliary heat strip control program also requires that participants have an electric water heater (for water heater control) and/or a centrally ducted heat pump (for auxiliary heat strip control).

Opt-outs. Participants may override two control events per device and per control season by contacting PEC and requesting an exemption from a partial or whole control event. If more than two overrides/exemptions are requested in a single season, the participant will forfeit his or her next annual credit and may be removed from the program.

Incentives. Each participant receives as an incentive a one-time bill credit of \$25 upon joining the program, and then an additional \$25 bill credit annually per device controlled to encourage continued participation.

Marketing. PEC is responsible for all marketing of the EnergyWise program. Leads for participation are generated through a mix of direct mailings, bill inserts and advertisements in select media.

1.3 *Reported Program Participation*

This sub-section reports the overall program participation for the summer and winter EnergyWise program. The EM&V participation sample sizes for the summer and winter program may be found in Section 2 below.

Eight DR events were called in the summer of 2011 for all participants in the EnergyWise program, and, as of the final event there were nearly 65,000 customers with a total of almost 85,000 central A/C units participating. Over January, February and March of 2012, two DR events were called for all participants and, as of the final event for non-EM&V participants, there were 4,301 customers that had joined the winter program.

The date, time and length of each event as well as the number of participants and A/C units at the time of each event are shown in Table 2, below.

¹PEC received approval in 2012 to allow tenants to participate in the program going forward, subject to some eligibility criteria and the landlord's approval. More details may be found at: <https://www.progress-energy.com/carolinas/home/save-energy-money/energy-efficiency-improvements/energy-wise/index.page>

Table 2: Overall Summer 2011 Program Participation by Event

Date	Start Time	End Time	Event Length (Hours)	Number of Participants	Number of A/C Units	Cycling Strategy
31-May-11	16:00	17:30	1.5	57,662	75,935	50%
1-Jun-11	16:00	18:00	2.0	57,732	76,023	50%
12-Jul-11	15:00	18:00	3.0	61,292	80,445	50%
22-Jul-11	15:00	17:30	2.5	62,230	81,619	50%
29-Jul-11	15:00	17:30	2.5	62,829	82,371	50%
4-Aug-11	15:00	18:00	3.0	63,244	82,862	50%
8-Aug-11	15:00	18:00	3.0	63,366	83,012	50%
25-Aug-11	16:30	17:00	0.5	64,803	84,786	100%

Source: PEC EW Control Event Tracking Report

The date, time and length of each winter event, as well as the number of participants that had joined the program by the date of the event are shown below.

Table 3: Overall Winter 2012 Participation by Event and Device Controlled

Date	Start Time	End Time	Event Length (Hours)	Water Heater Participants	Aux. Heat Strip Participants	Total Participants (1)
4-Jan-12	6:30	9:30	3.0	3,643	2,330	4,165
13-Feb-12	6:00	8:23	2.4	3,761	2,427	4,301

(1) Note that many participants have both water heater and auxiliary heat strips controlled so the total participants will be less than the sum of participants by device category.

Source: PEC Rebate Delivery Data

2. Evaluation Methods

This section describes the methods used in estimating load impacts and in evaluating customer satisfaction. The evaluation was conducted in four distinct but inter-related components. Following is a brief summary of the methods used for each of the four components:

1. **Demand Impact Evaluation** – the estimation of historic summer 2011 and winter 2012 curtailment impacts and the forecast of curtailment capability under different conditions, going forward. Impacts were estimated using device-specific logger data and an econometric technique known as “fixed effects”, the industry standard for DR program evaluations.
2. **Device Responsiveness Analysis** – the estimation of the percentage of devices that did not respond, or only partially responded, to PEC’s control signal. For A/C devices, estimation of the responsiveness rate was accomplished through a comparison of logged demand immediately prior to the beginning of the curtailment period and logged demand shortly after the start of the curtailment period. For auxiliary heat strip devices a member of the evaluation team examined data plots of individual device/event-day pairs and assigned each one to a responsiveness category based on a decision tree.
3. **Indoor Temperature Impact Evaluation (Summer Only)** – the evaluation of the average impact that curtailment had on indoor temperatures, and an analysis of principal drivers of indoor temperature change during summer events. Evaluation of the distribution of changes in indoor temperature relied on summary statistics based on indoor temperature data recorded by loggers. Analysis of the principal drivers of indoor temperature change used basic regression techniques. This analysis was conducted only for the summer events.
4. **Participant Perception Evaluation** – an analysis of four surveys of EnergyWise participants put into the field shortly after a number of August curtailment events and two surveys of participants put into the field shortly after the February and March² curtailment events. This analysis makes use principally of cross-tabulations and summary statistics obtained from the summary data.

2.1 Demand Impact Evaluation

Demand reduction and snapback impacts were estimated using fixed effects regression analysis applied to participant interval data, weather data and data flags indicating the intervals in which events took place. The remainder of this sub-section details the data and the econometric method used in the analysis. 5.2 Appendix G and Appendix H provide further discussion of the regression models used.

2.1.1 EM&V Participants and Events

The estimated impacts presented in this evaluation report are based on a sample of participants from the overall group that agreed to have data-loggers installed so that each curtailed device’s consumption could be monitored in isolation of the rest of household demand. This sample of participants was also

² Only the EM&V participants were subject to the March events. For the purposes of the survey, these became “placebo” events for the non-EM&V participants.

subjected to more and sometimes longer events than the overall sample in order to provide the evaluation team with more data points from which impacts could be estimated.

Altogether 100 A/C participants' households were equipped with data loggers intended to collect short-interval demand data from the 131 A/C units installed there, 56 water heater participants' households were equipped with data loggers to collect demand data from the 58 water heaters installed in those homes, and 37 auxiliary heat strip participants' households were equipped with data loggers to collect demand data from the 39 auxiliary heat strips installed in those homes³. No data was available for the A/C curtailment event on May 31.

The date, time and length of each event as well as the number of EM&V sample participants and A/C units for which the evaluation team has reliable interval data at that time of each event is shown in Table 4, below. The same data is shown for water heater and auxiliary heat strip EM&V participants in Table 5 and Table 6. Note that a 100% cycling strategy was used for all devices and all events in winter.

Table 4: A/C EM&V Sample Participation

Date	Start Time	End Time	Event Length (Hours)	Number of Participants	Number of A/C Units	Cycling Strategy
31-May-11	16:00	17:30	1.5	0	0	50%
1-Jun-11	16:00	18:00	2.0	94	122	50%
9-Jun-11	15:30	17:30	2.0	93	121	50%
22-Jun-11	16:15	18:15	2.0	93	120	65%
12-Jul-11	15:00	18:00	3.0	92	117	50%
13-Jul-11	16:00	17:00	1.0	92	117	50%
22-Jul-11	15:00	17:30	2.5	91	113	50%
29-Jul-11	15:00	17:30	2.5	91	113	50%
4-Aug-11	15:00	18:00	3.0	90	111	50%
8-Aug-11	15:00	18:00	3.0	89	109	50%
22-Aug-11	15:00	17:00	2.0	89	109	75%
25-Aug-11	15:30	16:30	1.0	89	109	100%

Source: Navigant Logger Data

³ These numbers all reflect participation at the start of the sample period. Note that due to technical problems and drop-outs they tended to be somewhat lower at the end of the sample period than at the beginning.

Table 5: Water Heater EM&V Sample Participation

Date	Start Time	End Time	Event Length (Hours)	Number of Participants	Number of Water Heaters
4-Jan-12	6:30	9:30	3.0	55	57
13-Jan-12	6:00	9:00	3.0	56	58
13-Feb-12	6:00	9:00	3.0	56	58
5-Mar-12	6:00	9:00	3.0	56	58
6-Mar-12	6:00	9:00	3.0	56	58

Source: Navigant Logger Data

Table 6: Auxiliary Heat Strip EM&V Sample Participation

Date	Start Time	End Time	Event Length (Hours)	Number of Participants	Number of Aux. Heat Strips
4-Jan-12	6:30	9:30	3.0	37	39
13-Jan-12	6:00	9:00	3.0	37	39
13-Feb-12	6:00	9:00	3.0	36	38
5-Mar-12	6:00	9:00	3.0	36	38
6-Mar-12	7:00	9:00	2.0	36	38

Source: Navigant Logger Data

2.1.2 Data Used for Impact Evaluation

1. Three minute interval logger data, from loggers connected to each participating A/C unit, electric water heater or auxiliary heat strips in the EM&V participants' home.
2. Outdoor temperature from 14 NOAA weather stations in PEC's service territory, shown in Table 7, below⁴.

⁴ For the winter analysis only Asheville weather was used.

Table 7: Weather Stations (Airports)

Station Name	Call-Sign
Henderson Oxford	KHNZ
Marion County	KMAO
Hartsville Regional	KHVS
Sanford	KTTA
Wilmington International	KILM
Fayetteville Regional-Grannis	KFAY
Raleigh-Durham International	KRDU
Kinston Regional	KISO
Jacksonville AWOS	KOAJ
Craven County Regional	KEWN
Florence Regional	KFLO
Asheville Municipal	KAVL
Asheboro Regional	KHBI
Goldsboro-Wayne Municipal	KGWW

Source: NOAA

2.1.3 Data Collection

In May 2011, the EM&V team installed current loggers on all outdoor AC compressors for 100 pre-recruited homes. When possible, the field technicians enclosed the data loggers inside the AC electronics access panel. If there was no room inside the panel, weatherproof loggers were mounted to the outside of the air conditioner on the most sheltered side of the unit. The data loggers were set to log at 3 minute intervals beginning June 1st for a period of 3 months. In addition to the current data-loggers, an indoor temperature logger was installed at each thermostat inside the house, also logging at 3 minute intervals. The field technicians collected other relevant information while onsite including home square footage, construction vintage, landscape shading, A/C age and condition, and spot power, voltage, and power factor measurements with the compressor running.

In November and early December 2011, the EM&V team installed current loggers on all switched winter-peak devices for 77 pre-recruited homes. The field technicians enclosed the data loggers inside the main circuit breaker panel, where all circuits in the house are easily accessible for logging. The technicians logged only the circuits with loads switched by the program: water heaters and air handling units (AHUs) containing auxiliary strip heaters. The data loggers were set to log at 3 minute intervals beginning December 12th for a period of 3 months. In addition to the current data-loggers, homes with switched auxiliary strip heaters had an indoor temperature logger installed at each thermostat inside the house, also logging at 3 minute intervals. The field technicians collected other relevant information while onsite including home square footage, construction vintage, number of stories, equipment information, and spot power, voltage, and power factor measurements with the loads running.

2.1.4 Data Quality Control

Upon retrieval, the data loggers were downloaded and batch-processed. The QC process involved three steps: visual inspection of each logger file, visual inspection of field photographs and notes, and discarding of bad data. First, all logger interval data were plotted for inspection. If data appeared suspect, the analysis team reviewed the field photographs and notes to determine the cause for the bad data. Logger malfunctions and faulty sensors caused some erroneous data. In other cases, the installer

made an error during the installation so the logger was recording current from the wrong wire. In all cases, the bad data were discarded.

2.1.5 Method for Estimating Demand Impacts

The evaluation team used an econometric technique known as “fixed effects” regression to estimate the impacts of the various types of device curtailed. Fixed effects regression is a form of linear regression commonly used in estimating the impact of DR programs. The technique is applied to a set of observations of some variable of interest (in this case electricity demand) from a number of different individuals (i.e., program participants) – also known as longitudinal or panel data – over time. Fixed effects regression assigns each individual participant his or her own dummy variable. In this way, the analyst may control for each individual’s time-invariant characteristics such as the size of a participant’s home, its orientation, etc. The fixed effects regressions were applied to quarter-hourly data, obtained by taking the average of the five three-minute interval observations within each fifteen minute period for each logged device.

For the summer analysis, the evaluation team estimated four regression equations to obtain the average per-household impacts presented below: one for each of the cycling strategies employed by PEC: 50%, 65%, 75% and 100%. The reader may recall that although there were eight EM&V 50% cycling events for which the evaluation team has data there was only a single event for each of the other cycling strategies, making the results for the 50% events the most robust in this report.

For the winter analysis, three regressions were used to obtain the average per-household impacts: one for water heaters and two for auxiliary heat strips. Two regressions were required for auxiliary heat strips, one for devices that were completely responsive, another for devices that were only partially responsive. The weighted average of the outputs of these regressions, and the average number of devices per household were used to generate the average per-household impact.

A formal model specification with additional input variable detail may be found in the appendices, Appendix G and Appendix H of this report.

2.2 Method for Estimating Device Responsiveness to Curtailment Signal

As part of its evaluation of the EnergyWise program, the evaluation team has endeavored to estimate how many A/C units and how many auxiliary heat strips did not respond to PEC’s control signal. The method used for estimating device responsiveness differs for the summer and winter data. The following two sub-sections briefly outline these methods.

2.2.1 Summer Device Responsiveness

Two-way communication sufficient to track whether A/C units within the EM&V sample responded to PEC’s control signal was not deployed as part of this program. As such, the evaluation team estimated the percentage of devices that did not respond to the control signal for each event by comparing each A/C unit’s average level of demand in the hour immediately prior to each event, with its average level of demand in the hour that begins thirty minutes into each event.⁵ A device was determined to have failed to curtail if its average level in demand did not fall by some threshold percentage compared to the hour

⁵ For single hour events, the prior hour was compared with the entire event hour.

preceding the hour. The impacts section below discusses the thresholds used, and the analysis that led to the final threshold actually used.

2.2.2 Winter Device Responsiveness

Early diagnostics of device responsiveness revealed two important findings:

1. A very high percentage of auxiliary heat strips had failed completely to respond to PEC's curtailment signal, and;
2. In a large number of cases auxiliary heat strips appeared to only partially respond to the curtailment signal.

Due to the smaller number of event/ device pairings than in the summer data, an alternative evaluation method was implemented. A daily plot of three-minute interval data for each event-day/auxiliary heat strip pair was examined and assigned to one of the following categories based on a decision tree (guidelines of the decision tree are described in more detail in Appendix D):

- Completely responsive;
- Partially responsive;
- Non responsive, or;
- Not in use

Diagnostics of the water heater logger data indicated that the overwhelming majority of devices responded to the curtailment signal, and so a responsiveness analysis comparable to that applied to the auxiliary heat strips was not undertaken.

2.3 Method for the Analysis of Indoor Temperature Changes During Events

For this part of the analysis, the change in indoor temperature is defined as the difference between the average indoor temperature observed in the hour preceding each curtailment event and the highest indoor temperature observed either during the event itself, or in the hour following the event. This last criterion was included due to the evaluation team's observation that indoor temperature change (as might be expected, given the physics of air exchange) tends to lag slightly behind A/C curtailment. This analysis makes use of regression techniques to estimate the relative impacts of the principal drivers of curtailment-induced changes in indoor temperature (e.g. outdoor temperature, cycling strategy, and length of curtailment).

This analysis focuses exclusively on A/C units that were determined to have successfully curtailed, although in the impact section below, the evaluation team demonstrates that including devices that were non responsive, as well as A/C units that were not on before or after the event, adds little useful information to the analysis.

2.4 Participant Perception Evaluation Method

To evaluate participants' perceptions of the program, including whether participants notice when an event took place and their reaction to the impact of various cycling strategies on their comfort, the

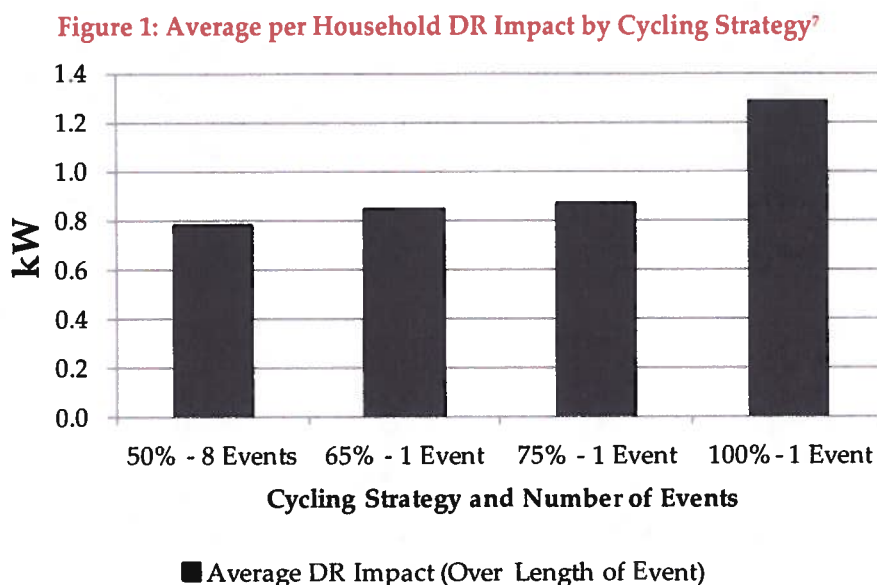
evaluation team conducted four different surveys during the summer season and two during the winter season.

Three surveys were conducted shortly after actual curtailment events on August 8th, August 22nd, August 25th (all 2011) and February 13th and March 5th and 6th (all 2012). In addition, a survey was conducted shortly after August 10th even though an event did not occur. The principal purpose of this “placebo” event was to allow the evaluation team to obtain a qualitative evaluation of the survey bias on the responses of participants. It should be noted that the August 22nd and the March 5th and 6th events applied only to EM&V participants, so that for non-EM&V participants there were effectively four placebo events.

3. Summer Load Reduction Impacts

This section of the report is devoted to the estimated program impacts on summer demand and is divided into two sub-sections: 1) the first will discuss the estimated impacts of the actual curtailment events in the summer of 2011, and 2) the second will discuss the estimated summer capability of PEC's EnergyWise program.⁶

The estimated DR impact by cycling strategy is shown in Figure 1, below. Note that these impacts are not weather-corrected and that on average the 50% cycling events were warmer than the 65%, 75% and 100% cycling events.



Source: Navigant Logger Data and Analysis

The evaluation team's principal findings regarding summer event demand impacts are as follows:

- The estimated impacts of 0.78 kW for 50% events and 1.28 kW for the 100% event are at the expected level for residential A/C direct load control programs, given the temperature observed at the time of the events. The forecast capability of the program is also at the expected

⁶ The estimated or forecast capability refers to the evaluation team's prediction of the impact PEC could expect to observe if an event were called at some set of given temperatures, over some set of given hours. In this second sub-section, a small sample of all the possible capability scenarios is discussed. The evaluation team has provided in 5.2Appendix G, however, all of the parameter estimates required for PEC or other interested parties to generate their own capability scenarios.

⁷ Note that these impacts are on average per household across all EM&V households, including those in which the A/C unit was estimated not to have responded to the curtailment signal. With an average of 11% devices estimated to fail to respond to the curtailment signal per event, had all of the non-responsive devices been responsive, the approximate average impacts for the 50%, 65%, 75% and 100% events would have been, respectively: 0.88 kW, 0.94 kW, 0.97 kW and 1.44 kW.

level. At a common temperature of 90 degrees Fahrenheit, the 50%, 65%, 75% and 100% cycling strategies would have a forecast capability of approximately 0.6 kW, 0.8 kW, 1 kW, and 1.3 kW of demand reduction per home, respectively. At 100 degrees the average demand reductions would expected to be approximately: 0.95 kW, 1.2 kW, 1.5 kW and 1.9 kW for each of the four cycling strategies. These are in line with findings published by the Lawrence Berkeley National Laboratory in a study of direct load control impacts under different cycling strategies.

- **Impacts are approximately proportionate to the cycling strategy used, when adjusted for temperature.** That is, all else equal (particularly weather), a 100% cycling strategy will yield roughly twice the demand impact of a 50% cycling strategy and a 75% cycling strategy will yield roughly one and a half times the demand impact of a 50% cycling strategy.
- **Snapback demand impacts sometimes last more than four hours following the event, with the increase in demand in any given hour being approximately 25% - 50% as large as the average estimated demand reduction during the period of the event.** The magnitude of snapback appears to be affected more by the length of the curtailment than the cycling strategy used. The two single hour events both had the smallest indoor temperature rise of all events, resulting, in the case of the 100% cycling event, in a snapback lower than that of the average 50% cycling event in the period immediately following the curtailment event.
- **In aggregate across all events in the summer of 2011, the program is estimated to have delivered an average of 55 MW of DR curtailments.** Should PEC apply a more aggressive cycling strategy at present levels of program participation, the program could potentially deliver over 100 MW of DR curtailment capability on days with temperatures in the high 90s.

Evaluations of demand-side management programs typically also estimate a net-to-gross (NTG) ratio based on the evaluated percentage of demand reductions which may be ascribed either to program spillover (which increases the NTG) or to free-ridership (which reduces it). Free ridership is typically defined as the percentage of demand reductions that would have occurred anyway, absent the presence of the program. Spillover is typically defined as incremental demand reductions undertaken by a program's participants not directly incented or promoted by the program administrator. In this case, since demand reductions are estimated in contrast to an implied estimated baseline⁸ which captures expected participant behavior absent an event, the evaluation team can confidently state that the free-ridership is 0 – absent the EnergyWise program, none of the observed demand reductions would have taken place. It is possible that there may have been some spillover resulting from the program (from participants becoming more aware of their sites' consumption profiles, for example), however it is likely impossible to estimate such an effect in a sufficiently robust manner and the assessment of such impacts is beyond the scope of this report.

Since spill-over cannot be robustly estimated, and since free ridership must, by program design, be considered to be zero, the evaluation team considers the EnergyWise Program to have a net-to-gross ratio of 1.

⁸ That is, the average level of behavior implied by the estimated parameter values of the regressions used.

This section is divided up into two principal sub-sections:

1. **Historic estimated load impacts:** that is, the estimated average per household impacts that the program has generated for actual days on which events were called. This section also discusses snapback, aggregate program-level impacts and demonstrates the reasonableness of the regression model by comparing actual and model-predicted demand graphically. This sub-section also provides the average energy conservation achieved by the program by cycling strategy.
2. **Forecast DR capability impacts:** that is, the estimated average per household impact for a variety of different temperatures. In some EM&V reports these are referred to as “ex ante” impacts. Capability forecast by temperature is provided at both the individual participant level, and in aggregate at the program level.

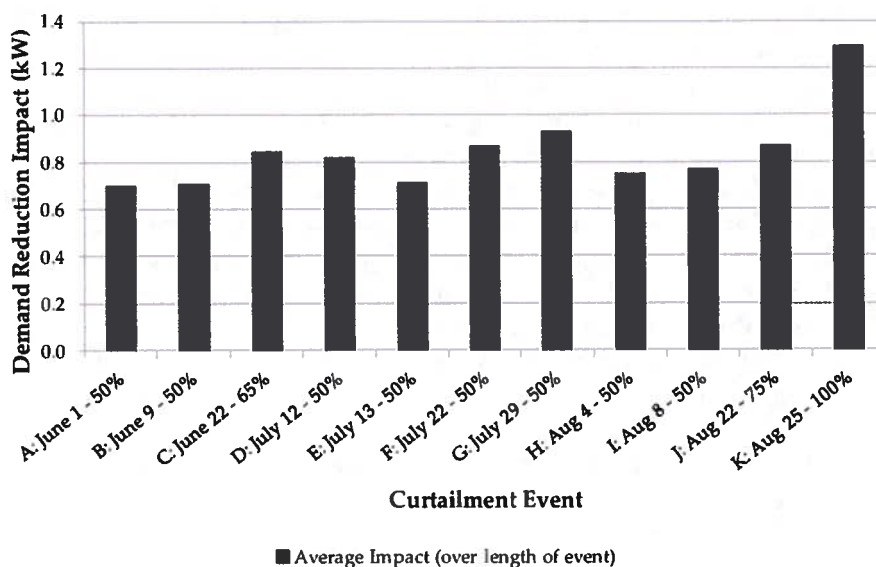
3.1 Historic Estimated Load Impacts

In this section the estimated historic demand impacts will be discussed. These are the impacts estimated by the evaluation team for the actual events that were called in the summer of 2011.

3.1.1 Event-Specific Impacts

DR impacts, by event are shown in Figure 2, below and in Table 8, below that. The reader should note that the average impacts discussed here are just that – the average per household impact across all participating EM&V households. This average includes all participating devices, including those suspected by the evaluation team of either failing to curtail or of being connected to unused A/C units (see Appendix A).

Figure 2: Average per Household Event DR Impact – by Event



Source: Navigant Logger Data and Analysis, NOAA Weather Data

Table 8: Average per Household Event DR Impact – by Event

Event	Cycling Strategy	DR Impact (kW)	Avg. Outdoor Temp (F) During Event	Event Length (Hours)
A 1-Jun-11	50%	0.70	91	2.0
B 9-Jun-11	50%	0.70	91	2.0
C 22-Jun-11	65%	0.84	91	2.0
D 12-Jul-11	50%	0.82	96	3.0
E 13-Jul-11	50%	0.71	91	1.0
F 22-Jul-11	50%	0.86	97	2.5
G 29-Jul-11	50%	0.93	99	2.5
H 4-Aug-11	50%	0.75	94	3.0
I 8-Aug-11	50%	0.76	94	3.0
J 22-Aug-11	75%	0.86	87	2.0
K 25-Aug-11	100%	1.28	90	1.0
Overall Average for 50% Events		0.78	94	2.4

Source: Navigant Logger Data and Analysis

Several features of Table 8 stand out and merit further discussion.

First and most obviously, Event K, the 100% cycling event that lasted an hour and was called on August 25th, was also the curtailment event with the largest demand impact, of nearly 1.3 kW on average during the event. Perhaps even more note-worthy is the fact that Events C (June 22, 2 hours) and J (August 22, 2 hours), the single 65% cycling event and 75% cycling event respectively, do not seem to have impacts that are very much different for those observed for the 50% cycling events.

This counter-intuitive effect is in fact simply due to the exterior temperatures. Compare the impact of Event C (65% cycling, 0.84 kW) with those of Events A and B (both 50% cycling, 0.701 and 0.703 kW impacts respectively) and compare the temperatures during those events. EM&V participants were, during Event C (65% cycling) subject to an average temperature of 91.2 degrees, whereas for Event A and B (both 50% cycling) participants were subject to an average temperature of 91.4 and 90.9, respectively. Put simply, it can be clearly seen that when there are similar temperatures prevailing, the 65% cycling strategy will certainly lead (as expected) to higher demand impacts. The same is true of the 75% cycling strategy – the relatively low impact for the single 75% cycling event called (Event J) may safely be ascribed to the fact that the average event temperature during that event was the lowest average temperature observed across all events (87 degrees).

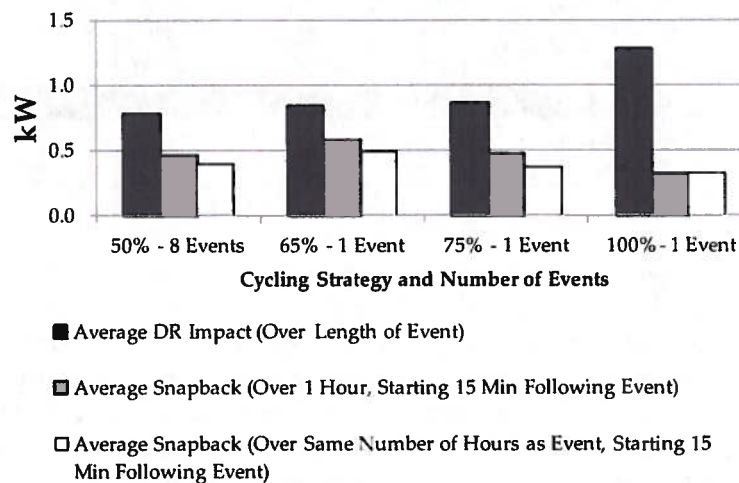
3.1.2 Demand Reduction and Snapback Impacts by Cycling Strategy

Examining the average DR and snapback impacts per type of cycling strategy employed (see Figure 3 below), we see that on average impacts conform to expectations – the 50% events on average result in smaller demand impacts than the 65% event, the 65% event had a smaller demand impact the 75% event, etc. What is unexpected, however, is the very mild snapback effect estimated for the 100% event. The average snapback over two different periods is reported in Figure 3. The two types of snapback are:

- The average increase in demand due to curtailment occurring over the first full hour beginning fifteen minutes after the end of the curtailment event, and;
- The average increase in demand due to curtailment occurring over the same length of time as the curtailment period, beginning fifteen minutes after the end of the curtailment event.

The reason for starting the snapback period windows fifteen minutes following the end of the curtailment period (rather than immediately following it) is to allow for the fact that device signals are staggered – in the first fifteen minutes immediately following the curtailment period a certain percentage of devices will still be curtailing. Including the snapback for this fifteen minute period would result in snapback impacts that are biased downward.

Figure 3: Average Demand Reduction and Snapback Impact By Cycling Strategy



Source: Navigant Logger Data and Analysis

As noted above, it is surprising and unexpected that the snapback is so low for the 100% event⁹. Given the much larger demand reduction impact, one would naturally expect a correspondingly larger snapback impact. The most convincing reason for this anomalous result appears to be the time of day during which the event was called and the length of the event. This very short event (only a single hour) was called on the second coolest of all of the event days and had the earliest ending of all the events – it was over by 4:30 pm. Seven (all but one) of the 50% events, by contrast, ended at 5:30 pm or later. Given that the curtailment period ended prior to the end of the typical work day, it seems likely that, on average, there were fewer people going in and out of the house during, or immediately after, the curtailment period, reducing the escape of cool air.

This, combined with the very short length of the curtailment period, suggests that the house may not have warmed up sufficiently to impose a very large incremental load on the A/C unit when the cycling period ended. Evidence for this can be found in Figure 30 of Appendix B, below; examining the indoor temperatures of homes during the events shows that the single 100% one-hour event actually had the second-lowest indoor temperature during curtailment compared to all the other events. The lowest

⁹ Note that the 100% event lasted only a single hour, hence why both snapback impacts reported here are the same.

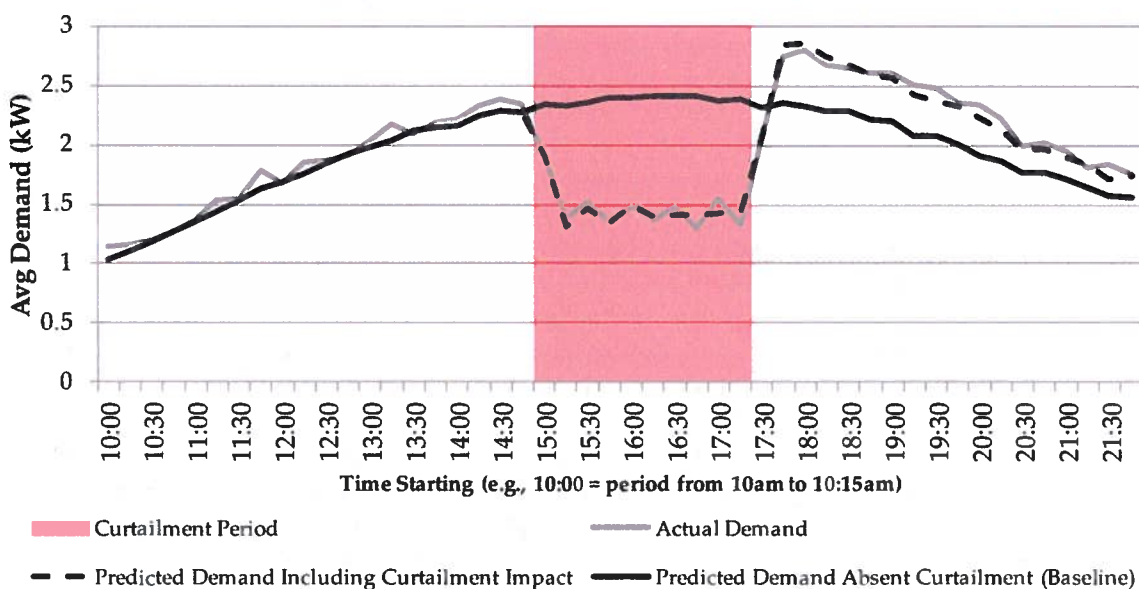
indoor temperature of all events was observed during Event E – a 50% event that also lasted only a single hour.

3.1.3 Reasonableness Checks – Historical Comparison

The evaluation team recognizes that econometric techniques may seem opaque or overly technical to some readers, and they may naturally wonder just how accurate the methods employed have been in estimating the impact of the various events. To provide reassurance to these readers, and as an internal reasonableness check, the evaluation team always compares the actual real average level of demand on event days, to that which is predicted by the model. If the two appear to be reasonably close when plotted on a chart, then the econometric model may be said to be doing a reasonable job of accounting for the manner in which demand varies due to changes in temperature or the presence of a curtailment event.

Two examples are provided as reasonableness checks. The first may be found in Figure 4 below which shows demand during Event G. During this event participants were exposed to the hottest average temperature of all events – almost 100 degrees Fahrenheit. The solid grey line indicates what the actual average level of household A/C load was on that day. The dashed black line is what the estimated econometric equation predicts average demand should have been for that day, inclusive of the impact of curtailment and given the temperature, humidity, etc. The solid black line is what the model would have predicted demand to be on the event day *had no event been called*. The estimated impacts discussed in the section above are the differences between the dashed black line and the solid black line.

Figure 4: Reasonableness Check, Event G, 29 July 2012, 50% Cycling Strategy

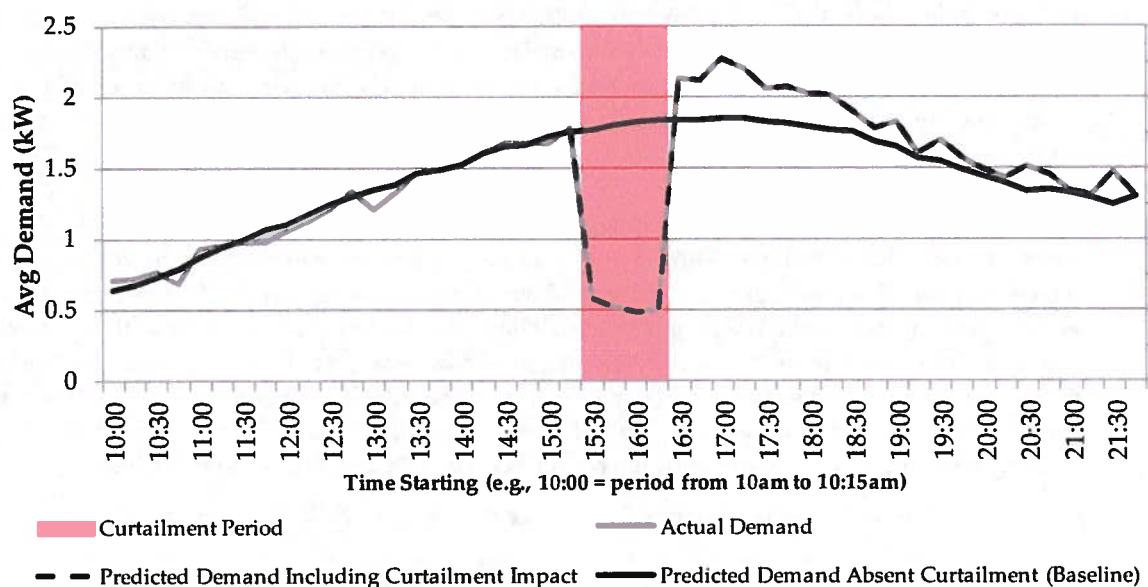


Source: Navigant Logger Data and Analysis

Note how closely the solid black line tracks the solid grey line prior to the curtailment period, rarely deviating by more than a tenth of a kW. This is a very strong indication that the model is doing a good job of estimating the true average impact that the curtailment event is having across the group of EM&V participants.

The second example provided for a reasonableness check is that of Event K, the 100% cycling event that took place August 25th and lasted for a single hour, as shown in Figure 5 below. As in the example in Figure 4, above, the grey line represents actual observed average levels of demand on that day, the dashed black line represents what, given the various weather and time-of-day factors, the model-predicted demand would be and the solid black line represents what the model would predict demand to be if no curtailment event were called.

Figure 5: Reasonableness Check, Event K, 25 August 2012, 100% Cycling Strategy



Source: Navigant Logger Data and Analysis

Note that the fit is even better in this example than the previous one. The tighter fit obtained in this case (compared with the 50% event shown in Figure 4 above) is a result of the fact that there was only a single 100% event in the sample. In the case of the 50% events, the model parameters were estimated in such a way that they provided the best fit on average across all events. Like all compromises this isn't perfect, leading to very small deviations between the grey and dashed black lines in Figure 4. There is only a single 100% event, so such compromises are not required and, due to a relatively large number of participants from whom to draw data, a very tight fit is obtained.

A unique equation could have been estimated for each 50% equation, and it is possible that a better fit would have been obtained proceeding in this manner instead of using a single model for all events. Such an approach would have yielded a poorer forecast of the overall average relationship between demand impacts and weather, time of day, etc. for 50% cycling events, however.

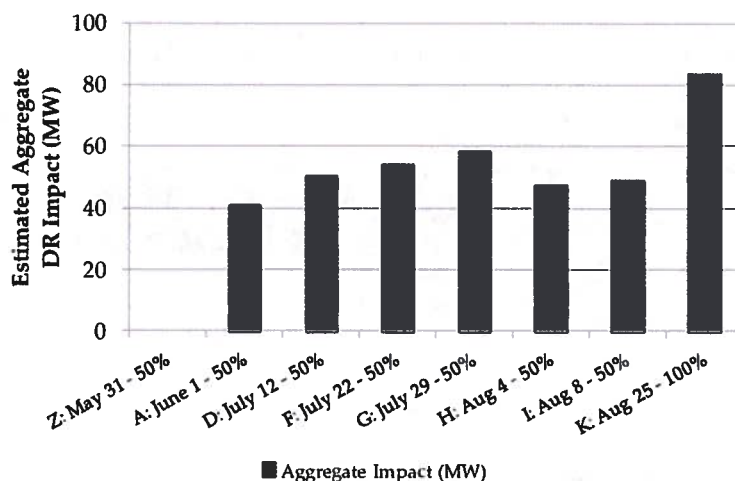
3.1.4 Aggregate Impacts

Thus far, discussion of the estimated historical demand reductions has concentrated on the average impact per participating household in the EM&V group. As noted above in Table 2, however, the EnergyWise program has had considerable success in recruiting participants, with between 57,000 and 65,000 participating in eight events over the summer of 2011. Extrapolating the estimated impacts for

each event out to the wider program will likely be of interest to PEC, and such an extrapolation may reasonably be undertaken given a few necessary assumptions.¹⁰

Figure 6 shows the estimated aggregate impact for each event. The labels on the horizontal axis indicate the date of the event and the cycling strategy used. The reader will note that although there is an Event A and an Event D, there is no Event B or C. These two events were curtailment events to which only the EM&V sample was subjected (on June 9th and 22nd, respectively).

Figure 6: Estimated Aggregate Impacts, Summer 2011



Source: Navigant Logger Data and Analysis and PEC Program Data

As would be expected, the pattern of demand reductions is very similar to that observed for the average participant level data. Differences between the relative levels of the various demand impacts compared to the average per-household results presented in Figure 2 are due entirely to the increasing levels of participation (as shown in Table 2).

¹⁰ The first of these assumptions is simply that the EM&V households are an accurate reflection of the distribution of households in the program population – put simply, the underlying assumption is that if the average EM&V household yielded an impact of 0.7 kW demand reduction for Event A (June 1, 50% cycling) then that will also be the average demand reduction provided by the program population. All of the 50% cycling events called for the program population, the timing and cycling strategy are identical for the EM&V sample (although the EM&V sample were subject to more events than the overall program population).

The second assumption is a bit more tenuous. Unfortunately the 100% event on August 25th to which non EM&V participants were subject was both half an hour shorter than that to which the EM&V sample was subjected and occurred slightly later in the day (between 4:30 and 5 pm, as opposed to between 3:30 and 4:30 pm for the EM&V sample). Thus the necessary operating assumption used to calculate the aggregate impact of the is that the average demand reduction impact for the 100% event will be the same for the program population as for the EM&V group, despite the shorter time window and the fact that it occurs later in the day.

The reader will also note that no aggregate impact is estimated for the May 31 event (referred to in Figure 6 as Event Z). There was no EM&V sample data for this date and therefore no historical impact was estimated for the EM&V sample that could be extrapolated out to the aggregate level.

3.1.5 Energy Conservation

The driving purpose of a demand response program is to reduce system peak demand and thus allow for investments in generation and infrastructure to be postponed – it is the capacity provided by such programs that provides program value. Typically, evaluations of direct load control demand response do not even estimate conservation impacts because they are so trivial. The effects of snapback (where curtailed demand is “made up” in the period following curtailment) and the fact that there are typically not more than a few events per season, each only a few hours mean that conservation impacts – where they exist – will be very small.

For completeness, however, the evaluation team has calculated the average energy conservation achieved in the summer of 2011 per hour of event curtailment, by control strategy. These impacts are presented in Table 9.

Table 9: Summer Energy Savings per Hour of Curtailment, by Cycling Strategy

Cycling Strategy	Energy Savings (kWh) per Hour of Event
50%	0.19
65%	0.22
75%	0.44
100%	0.68

Source: Navigant Logger Data and Analysis

Average energy savings per hour were calculated by taking the total energy reduction estimated during the curtailment period, less the energy increase due to snapback¹¹, divided by the number of hours of curtailment for each event. The results reported in Table 9 are a simple average of energy impacts by event cycling strategy

3.2 Forecast Curtailment Capability

An important component of the evaluation team’s task in estimating the impacts of curtailment events was to not just estimate the impacts of the historical events (those discussed in the previous sub-section), but to make a forecast of PEC’s DR capability at a variety of different temperatures. It is this forecast of capability that provides the truest estimate of a given DR program’s value as a system resource, since it provides PEC staff with an understanding of how much of a demand reduction the program may be counted on to deliver in future system peak conditions. This is also why it is the forecast DR capability¹² that should be used to calculate the benefits for any cost-benefit ratio test (e.g., total resource cost test or TRC).

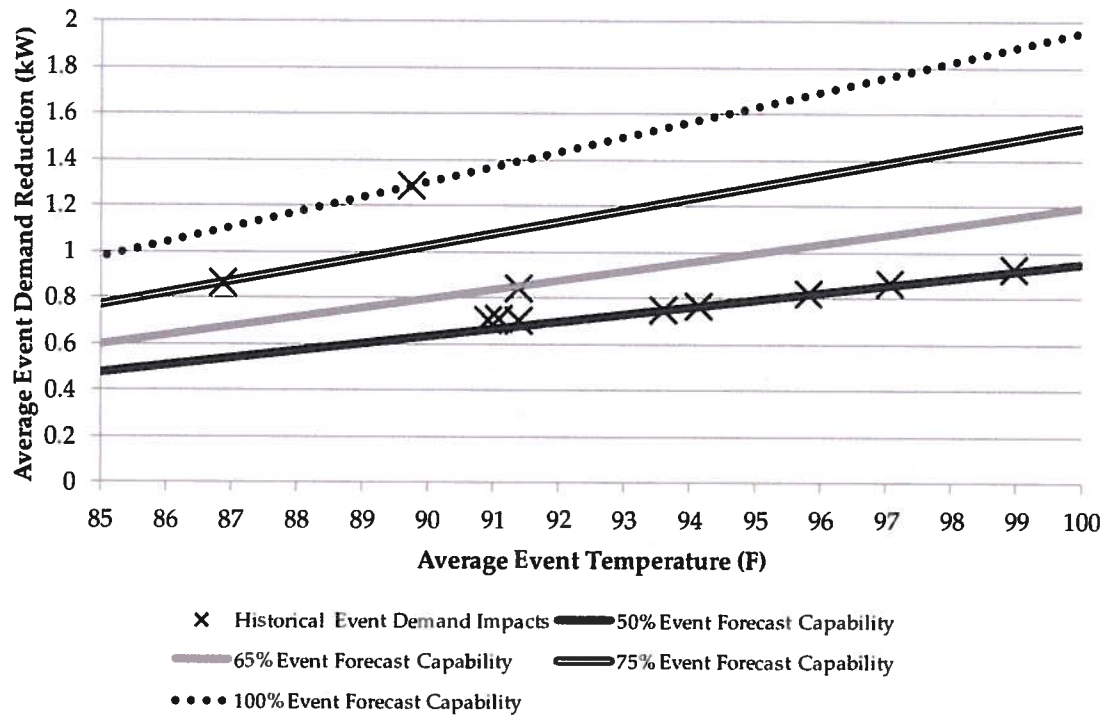
The forecast capabilities of the four examined cycling strategies are presented in Figure 7 below. Altogether there are five series of data plotted on the figure:

¹¹ In this case snapback energy increases were calculated as the estimated snapback impacts greater than zero that were estimated over the number of hours following the event equal to three times the number of hours of the event itself, or the hours occurring between the event and 10pm, whichever was smaller.

¹² In some jurisdictions this is sometimes referred to as an “ex ante” estimate of DR impacts. See for example the 2009 and 2010 evaluations of the Ontario Power Authority’s *peaksaver*® program, a residential and small business residential direct load control program: <http://www.powerauthority.on.ca/evaluation-measurement-and-verification/evaluation-reports>.

- The forecast capability of the *four different cycling strategies* at a variety of different temperatures, indicated by four different styles of line.
- The actual historical impacts of the events, indicated by crosses.

Figure 7: Forecast DR Capability – All Cycling Strategies



Source: Navigant Logger Data and Analysis

Forecast Capability Lines by Cycling Strategy

The four lines represent the average forecast DR capabilities of the various cycling strategies at a variety of different temperatures between 85 and 100 degrees Fahrenheit. The reader should note that these represent the average demand reduction that could be expected over a single event, and not at a single hour or fifteen minute interval. The parameter estimates and other figures required to reproduce these lines for any given fifteen minute interval (in which an event was actually called) are provided in Appendix G at the end of this report. Using the numbers provided in Appendix G the reader will be able to reproduce a capability line only for those periods in which a 2011 event was actually called (i.e., no capability could be forecast for a 100% cycling strategy between 4:30 and 4:45 pm since the only 100% event called in 2011 was between 3:30 and 4:30 pm).

The slopes of all these lines are such that at 70 degrees Fahrenheit there would be no DR impact resulting from curtailment. As noted above, 70 degrees was chosen as the threshold for calculating cooling degree hours (CDH) based on exploratory regressions for the 50% cycling events which suggested that very little A/C is in fact used at this temperature.

Actual Historical Temperature/Impact Combination Points

The crosses represent the observed average event temperature/estimated average event impact pairs for all of the summer 2011 events. These are averages across each event and not specific to any fifteen minute interval within the events. Appendix G contains the necessary parameter estimates and other inputs to allow interested readers to reconstruct these impacts either on average by event (as they are represented below) or else for individual fifteen minute intervals.

As has been noted several times, there was only a single event for the three more aggressive cycling strategies. Thus, slopes for the forecast capability lines were calculated based on the slope between the historical temperature/estimated impact combinations and the point at which that combination would be (0,0) – when the cooling degree hours are zero (70 degrees Fahrenheit) and thus the A/C curtailment DR impact would be expected to be zero.

The evaluation team believes that the forecast capabilities at various temperatures presented in Figure 7 above are as robust as the data allow. It must be pointed out, however, that for the more aggressive cycling strategies there are very few data points. The 50% cycling strategy forecast capability may be clearly seen on this graph to be quite robust – note the proximity of the crosses representing the 50% control event impacts to the forecast capability line.

There is no such easy verification possible for the other cycling strategies. Thus, although the forecast capabilities for the more aggressive cycling strategies are as robust as the data allow, PEC staff should exercise some caution applying these estimates in system planning exercises. The evaluation team would recommend that if PEC envisions itself wishing to count upon the EnergyWise program as a demand-side resource at more aggressive cycling strategies in the future, it should consider further testing the impacts that such strategies provide in the field.

Intriguingly, a Lawrence Berkley National Laboratory (LBNL) study examining different cycling strategies found very similar capabilities at various temperatures¹³, although at the upper limit, the capabilities estimated for PEC in this study are slightly more conservative than in the LBNL study. A comparison of the upper limit of forecast capabilities in both this and the LBNL study is shown in Table 10 below. The graph from which these figures are drawn may be found on page 14 of the LBNL report (citation below).

¹³ The LBNL study uses a temperature humidity index rather than simply temperature as the variable determining capability, but essentially the same conclusions as shown here may be drawn.

Table 10: Comparison of LBNL and PEC/Navigant Upper Limits of Forecast DR Capability

Cycling Strategy	Navigant/PEC Upper Limit of Forecast DR Capability (kW)	LBNL Upper Limit of Forecast DR Capability (approx.) (kW)
50%	0.95	1.1
65%	1.2	N/A
67%	N/A	1.5
75%	1.5	1.75
100%	1.9	2.5

Source: Navigant Logger Data and Analysis and LBNL Study¹⁴

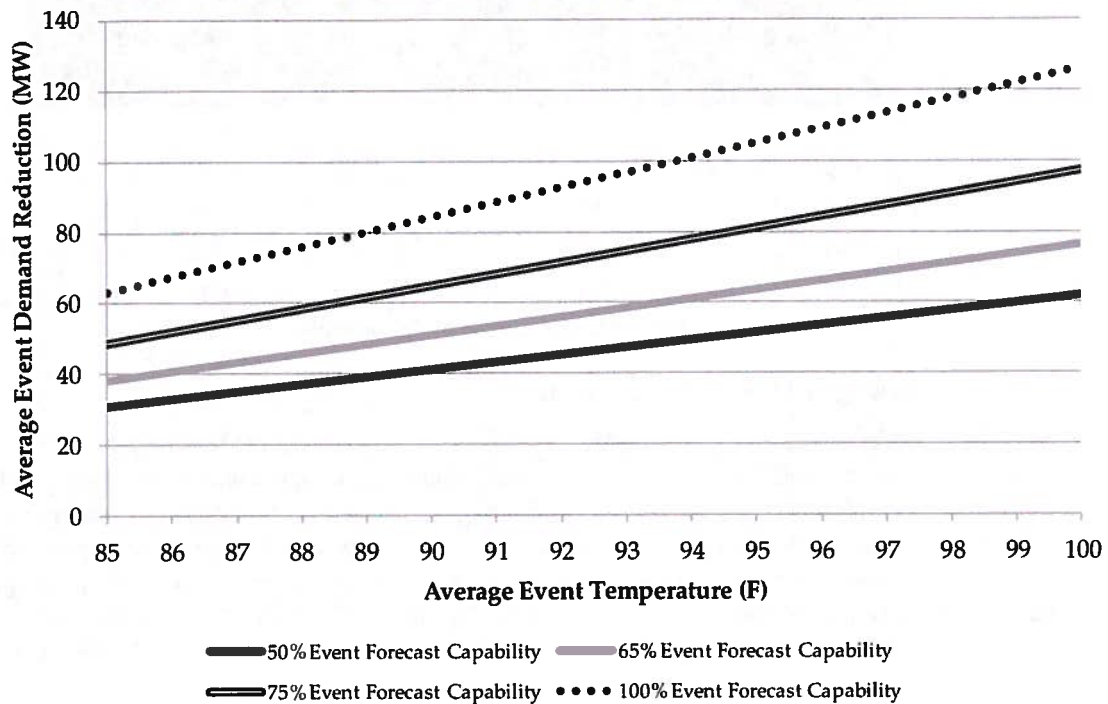
3.2.1 Aggregate Forecast DR Capability

As noted in the previous sub-section discussing historical impacts, a number of assumptions – some more tenuous than others – may be made to allow individual average impacts to be extrapolated out to the program population. To extrapolate forecast program capability an additional assumption regarding the level of program participation going forward must be made. To extrapolate aggregate capabilities, the evaluation team has conservatively assumed that the program population (of A/C participants) will stabilize at 65,000 participants (there were 64,803 at the time of the final 2011 summer event). The forecast capabilities at a range of different average event temperatures are shown below in Figure 8.

¹⁴ Heffner, Grayson *Regional Approaches to Monitoring and Verification of Load Management Programs*, Lawrence Berkeley National Laboratory, May 2007.

http://sites.energetics.com/MADRI/pdfs/Heffner_LBNL_ALMRegionalModel051407.pdf

Figure 8: Forecast EnergyWise Program Capability With 65,000 Participants



Source: Navigant Logger Data and Analysis and PEC Program Data

As may be seen in Figure 8, the EnergyWise program could have the capability to potentially offer more than 100 MW of DR during very hot summer afternoons. As noted previously, however, given the number of 100% cycling events called in the summer of 2011 this forecast should be used with caution. The evaluation team would recommend that such capability be confirmed by further EM&V 100% cycling events at a variety of outdoor temperatures before such a forecast is considered firm enough for inclusion in any system planning documents.

4. Winter Load Reduction Impacts

This section of the report is devoted to the estimated program impacts on winter demand. This section is itself divided into two sub-sections: the first will discuss the estimated impacts of the actual curtailment events in the winter of 2012, the second will discuss the estimated winter capability of PEC's EnergyWise program.

The second part, the estimated or forecast capability, refers to the evaluation team's prediction of what kind of impact PEC could expect to observe if an event were called at some set of given temperatures, over some set of given hours.

The average estimated impact per household for each type of device curtailed is presented in Table 11 below. Note that these impacts are averages across all households and devices, including those which were found by the evaluation team to be either non-responsive or only partially responsive. More details regarding non-responsive and partially responsive devices may be found in 5.2 Appendix D, below.

Table 11: Summary of Average Per-Household DR Impacts by Event and Device Controlled

		Event A 4-Jan-12	Event B 13-Jan-12	Event C 13-Feb-12	Event D 5-Mar-12	Event E 6-Mar-12	Average Over All Events
DR Impacts (kW)	HP Aux. Heat Strips	1.47	0.57	0.58	0.05	0.38	0.61
	Water Heaters	0.44	0.43	0.41	0.41	0.41	0.42
Avg. Outdoor Temp (F) During Event		18.4	24.5	24.9	42.0	28.5	27.6

Source: NOAA data, Navigant logger data and analysis.

The principal findings of the evaluation team's analysis of winter demand impacts are:

- **Water heater curtailment yields a very predictable impact - 0.42 kW on average -that is mostly insensitive to weather.** Water heater demand in the morning, driven by participants' morning showers, is remarkably consistent, as are the DR impacts of curtailment, regardless of weather.
- **Heat pump auxiliary heat strips yielded lower than expected DR impacts per household: 0.75 kW per household on event days where the temperature was less than 40 degrees Fahrenheit and only 0.05 kW on the event day where the temperature was 42 degrees Fahrenheit.** This was due to a very high rate of auxiliary heat strips not responding to the PEC curtailment signal – devices that completely responded to the PEC control signal had an estimated average DR impact across all events nearly two and a half times that reported for auxiliary heat strips in Table 11, above.
- **The magnitude of auxiliary heat strip load reductions increase at an increasing rate as the temperature falls.** That is, the relationship between auxiliary heat strip demand and outdoor temperature is not linear – the DR impact of curtailing auxiliary heat strips at 20 degrees

Fahrenheit will be more than twice that of curtailing auxiliary heat strips at 40 degrees Fahrenheit.

- **Snapback is much more pronounced for the winter program than for the summer, exceeding average demand reductions for a short period following each event.** The average snapback demand impact in the first hour occurring fifteen minutes after the end of the curtailment period is greater than the average DR impact realized over the curtailment event for both auxiliary heat strips and water heaters. For water heaters the average snapback demand impact in that hour can be more than twice the average DR impact realized over the curtailment event.
- **In aggregate, the program is estimated to have delivered an average of 4 MW of DR curtailments across all events in the winter of 2012.** Should PEC succeed in significantly improving the auxiliary heat strip response to its control signal, EnergyWise could potentially offer nearly 10 MW of winter peak DR on very cold mornings.

This chapter is divided into four parts – two principal sections each of which are divided into two sub-sections. They are:

1. **Historical Estimated Program Impacts**
 - Water Heaters per Household Impacts
 - Heat Pump Auxiliary Heat Strips per Household Impacts
 - Program Aggregate Historical Impacts
 - Average Energy Conservation Impacts
2. **Forecast Program Capability**
 - Water Heaters per Household Capability
 - Heat Pump Auxiliary Heat Strips per Household Capability
 - Program Aggregate Capability

4.1 *Historical Estimated Program Impacts*

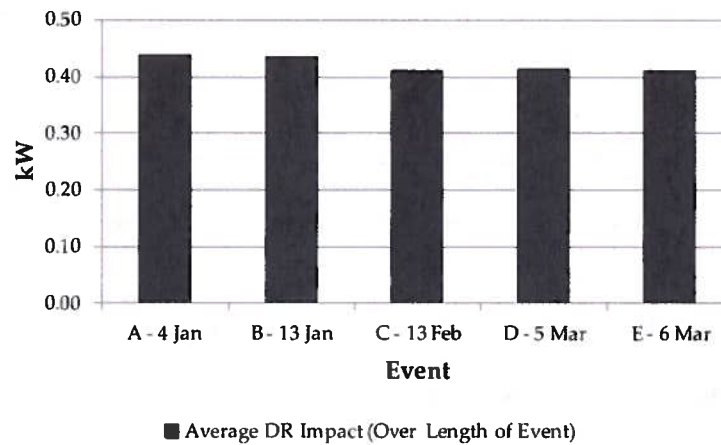
This section provides the estimated per-household impacts of curtailment in the winter of 2012 for water heaters and auxiliary heat strips and discusses the results.

4.1.1 **Historical Water Heater Impacts**

This sub-section discusses the average, per household impact of water heater curtailment. In addition to the average demand reduction impact for each event, snapback will be discussed. This section will also present a plot of actual event demand, predicted baseline demand (absent curtailment) and predicted demand including the effects of curtailment for an example effect in order to demonstrate the accuracy, or reasonableness, of the evaluation team's estimates of impact.

The average household impact for each water heater curtailment event is shown in Figure 9, below.

Figure 9: Average Water Heater DR Impact per Household per Event



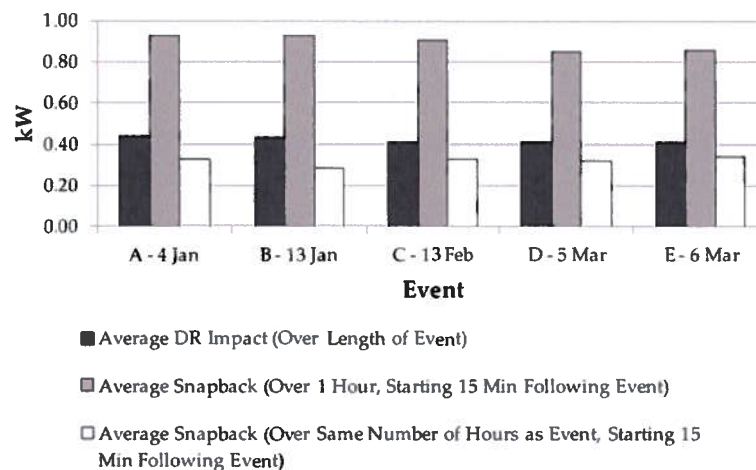
Source: Navigant Analysis

As may be seen, the demand reduction impact is remarkably consistent across all events. This is to be expected as most water heaters are located inside in semi-conditioned spaces and thus not greatly affected by outdoor temperature. Over the course of the entire event, the average demand reduction is approximately 0.4 kW.

The demand reductions shown in Figure 9 are reproduced in Figure 10, below. Also shown in this figure is the average impact of snapback over:

- The first hour beginning fifteen minutes immediately following the curtailment event, and;
- The period beginning fifteen minutes immediately following the curtailment event equal to the length of the curtailment event (e.g., if the curtailment event is three hours, the period over which the snapback is averaged is three hours).

Figure 10: Average Water Heater DR and Snapback Impact per Household per Event



Source: Navigant Analysis

Note that the degree to which the average snapback demand in the first hour and fifteen minutes immediately following the curtailment event exceeds the average demand reduction during the event. This is to be expected – over the curtailment period there is likely a considerable diversity in demand. Over the three hours the water heaters are curtailed, some would – absent curtailment - otherwise have been operating in the first hour and not the last two. Other water heaters would otherwise have been operating over only the final hour of curtailment, or only the second hour of curtailment, etc. Once the curtailment period ends, however, all of the water heaters that have been curtailed will begin operation simultaneously, resulting in a relatively high level of average per household demand.

Another factor driving the spike in demand immediately following the end of the curtailment period is likely due to the fact that electric water heaters typically have two heating elements. In many cases only one element is required to maintain tank set-point – a single element only may be required to “top up” the storage tank as hot water is being drawn from it or to compensate for standby losses. When the gap between the tank set-point and its actual temperature becomes sufficiently large, however, the second element may be engaged to quickly restore the set-point temperature. It seems probable that in many cases this is what is occurring in the period immediately following the curtailment period.

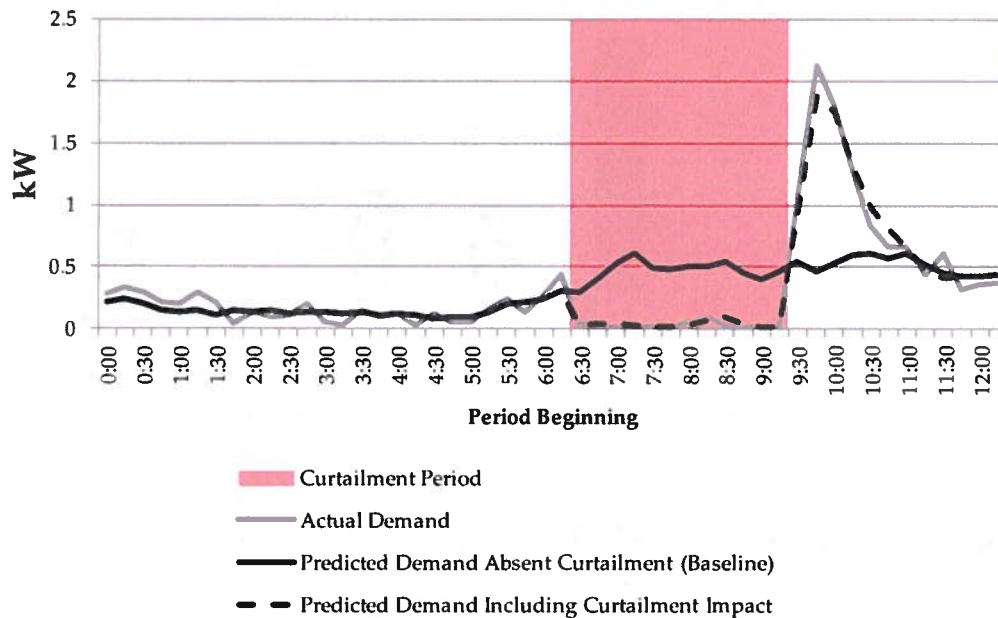
It is important to note that despite the spike in demand that occurs immediately following the curtailment period, water heater curtailment provides some modest energy conservation details of which may be found in 4.1.4, below.

This immediate spike in demand following the end of the curtailment period is clearly visible in Figure 11, below. This plot shows, from midnight until noon, for the 4th of January, 2012 event:

- The actual average water heater demand per household (grey line);
- The model predicted demand, had no curtailment event taken place (black solid line), and;
- The model predicted demand with curtailment (black dashed line).

Estimated demand impacts are calculated as the difference between the solid and dashed black lines.

Figure 11: Plot of Predicted and Actual Water Heater Demand for Event A – 4 Jan, 2012



Source: Navigant Analysis

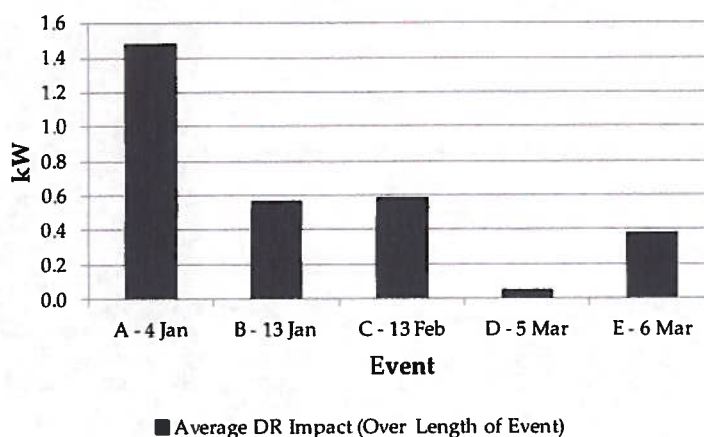
Note how closely the model predicted demand tracks the actual demand for this event. In particular, note how well the modeled demand (with curtailment) fits the actual demand during the event and immediately afterward, during the snapback period. This is a strong indication of the model's robustness and accuracy and affirms the reasonableness of the estimated impacts.

4.1.2 Historical Heat Pump Auxiliary Heat Strip Impacts

This sub-section discusses the average, per household impact of auxiliary heat strip curtailment as well as the average impact of auxiliary heat strip curtailment per device for those devices deemed to have been completely responsive to the curtailment signal and those devices deemed to have been partially responsive to the curtailment signal.

In addition to the average demand reduction impact for each event, snapback will be discussed. This sub-section will also present a plot of actual event demand, predicted baseline demand (absent curtailment) and predicted demand including the effects of curtailment for an example effect in order to demonstrate the accuracy, or reasonableness, of the evaluation team's estimates of impact. The average household impact for each auxiliary heat strip curtailment event is shown in Figure 12, below.

Figure 12: Average Auxiliary Heat Strip DR Impact per Household per Event



Source: Navigant Analysis

The reader should note that, as in Table 11, above, the DR impacts shown in Figure 12 represent the average per household impact of curtailment – this includes households where:

- The auxiliary heat strip responded completely to the curtailment signal;
- The auxiliary heat strip only partially responded to the curtailment signal;
- The auxiliary heat strip did not respond at all to the curtailment signal, and;
- Auxiliary heat strips were not in use at the time of the event (meaning no demand impact is possible).

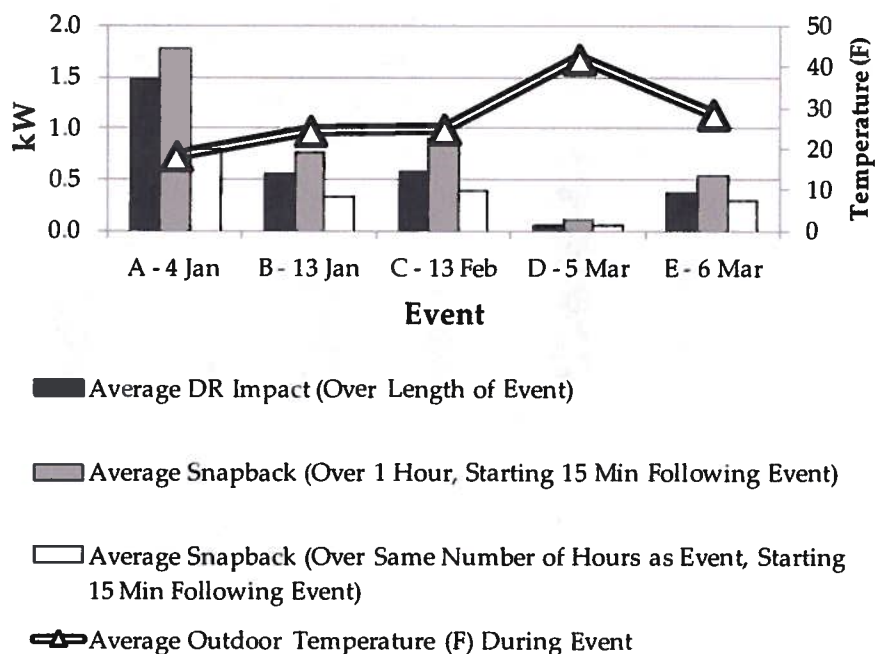
Further details on the definitions of these four categories and the distribution of participants between them may be found in Appendix D, below.

Unlike water heater curtailment, the DR impacts of auxiliary heat strip curtailment are highly variable. This is to be expected – by their very nature, heat strips are more sensitive to outdoor fluctuations than water heaters. As may be seen in Table 11 and Figure 12 the average household demand impact ranges from nearly 1.5 kW to almost no impact whatsoever for auxiliary heat strips.

The demand reductions shown in Figure 12 are reproduced in Figure 13, below. Also shown in this figure is the average outdoor temperature observed during each event and the average impact of snapback over:

- The first hour and fifteen minutes immediately following the curtailment event, and;
- The period immediately following the curtailment event equal to the length of the curtailment event (e.g., if the curtailment event is three hours, the period over which the snapback is averaged is three hours).

Figure 13: Average Auxiliary Heat Strip DR and Snapback Impact per Household per Event, with Average Outdoor Temperature During the Event



Source: Navigant Analysis and NOAA Temperature Data

Note that the immediate short-term snapback for auxiliary heat strips is, in proportion to the DR impact, considerably smaller than that of the water heaters. This reflects both the more consistent pattern of use of the auxiliary heat strips (on a non-event day) within the hours of the curtailment period. It also reflects the fact that unlike the water heaters (some of which may engage a second element to recover set-point), the capacity engaged during the snapback period is the same as would otherwise have been engaged during the curtailment period, had the device not been curtailed.

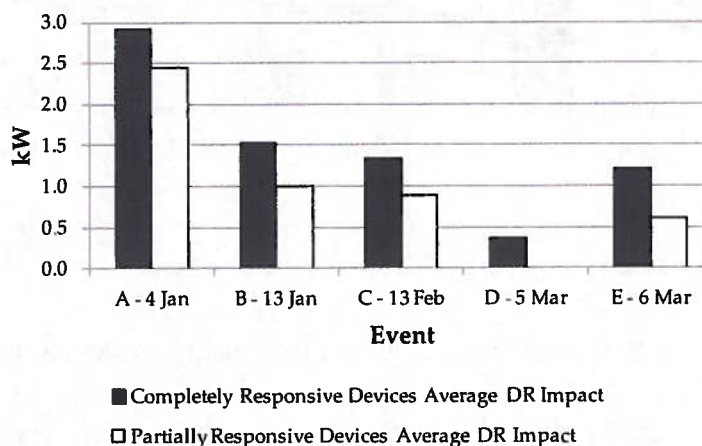
The sensitivity of the demand reduction to outdoor temperature is also noteworthy – on the warmest event day, there is almost no impact at all. This is due principally to the fact that auxiliary heat strips typically are only engaged when the outdoor temperature falls between 35 and 45 degrees Fahrenheit. For event D, when the temperature was 42 degrees F on average during the event, a very high proportion of auxiliary heat strips were not even in use, greatly reducing the average impact per household.

Unlike water heaters, or A/C units in the summer analysis, estimation of the impact of auxiliary heat strips was performed at the device level for each of the four types of curtailment signal response outlined above. A weighted average of these per-device impacts across the four categories¹⁵ was then multiplied by the average number of devices per household to obtain the average household-level impact. This approach was taken, as noted in Section 2, above, to improve the accuracy of the impact estimates.

¹⁵ Naturally, the impact for each event for units that either completely failed to respond to the curtailment signal or else were not in use at the time of the curtailment period is 0 kW.

The average DR impact for each event for devices that had a complete response to PEC's curtailment signal and those that had a partial response to PEC's curtailment signal are shown in Figure 14, below.

Figure 14: Average Auxiliary Heat Strip DR Impact per Device by Category of Device Response to Curtailment Signal¹⁶



Source: Navigant Analysis

Note that for Event D, only three participants showed evidence of some partial response to the curtailment signal and that the diversity of when the heat strips were active during the curtailment event was such that, on average, there was no estimated demand reduction impacts. More details regarding the number of participants by device response category may be found in Appendix D.

Navigant's regression model for each category of response to the curtailment signal performs well, in terms of predicting actual demand, although less well than for the water heaters. This is simply due to the number of observations in the sample, and the fact that water heater load is inherently more predictable than auxiliary heat strip load. Bear in mind for the two examples of the models' performance below (both for 4th of January, 2012) for devices that completely or partially responded to PEC's curtailment signal, the sample contained data for only nine (complete response) and twelve (partial response) participating auxiliary heat strips. This is in contrast with the model for the water heaters, which made use of the data of over 50 individual households.

The accuracy of the models estimated by the evaluation team may be observed in Figure 15 for completely responsive devices and Figure 16 for partially responsive devices, both below. These plots show, from midnight until noon, for the 4th of January, 2012 event:

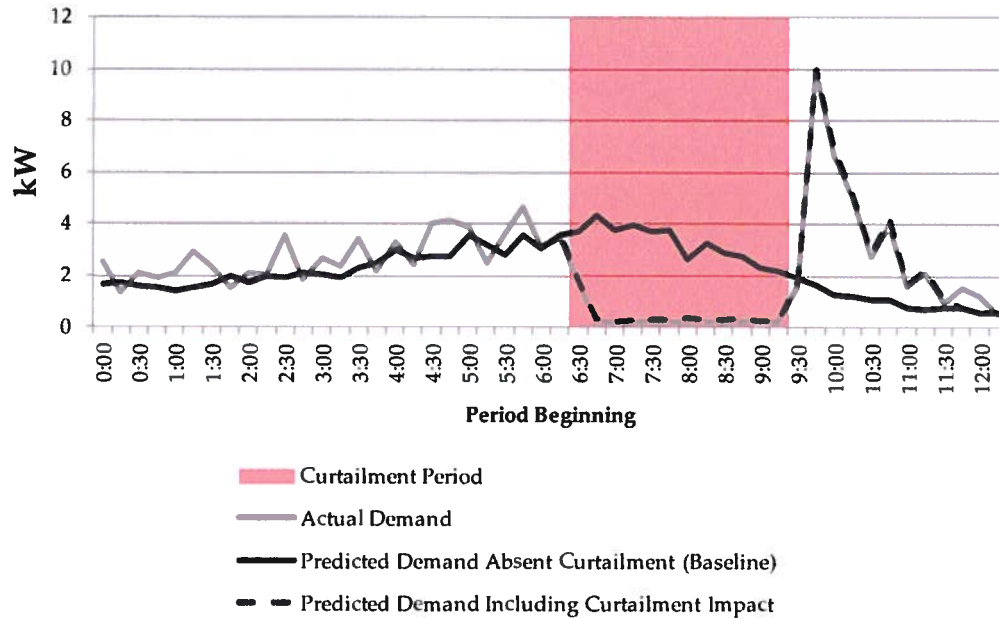
- The actual average auxiliary heat strip demand per device (grey line);
- The model predicted demand, had no curtailment event taken place (black solid line), and;

¹⁶ Note that the estimated DR impact for partially responsive devices on Event D was nearly zero, but slightly negative – a clearly nonsensical result. For practical purposes the evaluation team has considered that no impact was elicited for this event for partially responsive devices.

- The model predicted demand with curtailment (black dashed line).

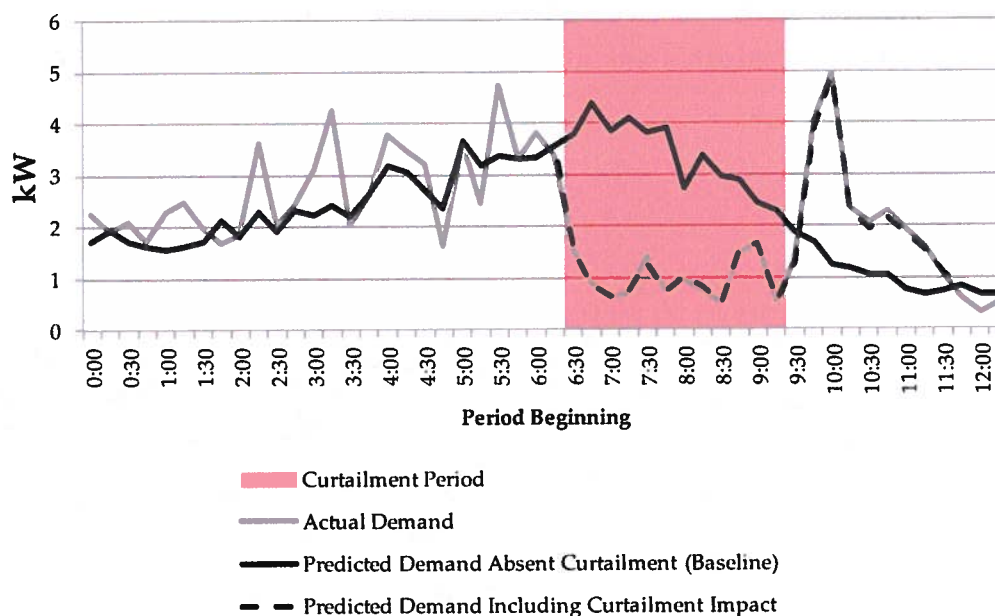
Estimated demand impacts are calculated as the difference between the solid and dashed black lines.

Figure 15: Plot of Predicted and Actual Auxiliary Heat Strip Demand for Completely Responsive Devices for Event A – 4 Jan, 2012



Source: Navigant Analysis

Figure 16: Plot of Predicted and Actual Auxiliary Heat Strip Demand for Partially Responsive Devices for Event A – 4 Jan, 2012



Source: Navigant Analysis

As noted above, neither model predicts the actual demand as accurately as that used to estimate the impacts of water heater curtailment, mostly due to a smaller sample size. The model for both completely and partially responsive devices appears to provide a reasonably accurate and robust prediction of actual auxiliary heat strip demand.

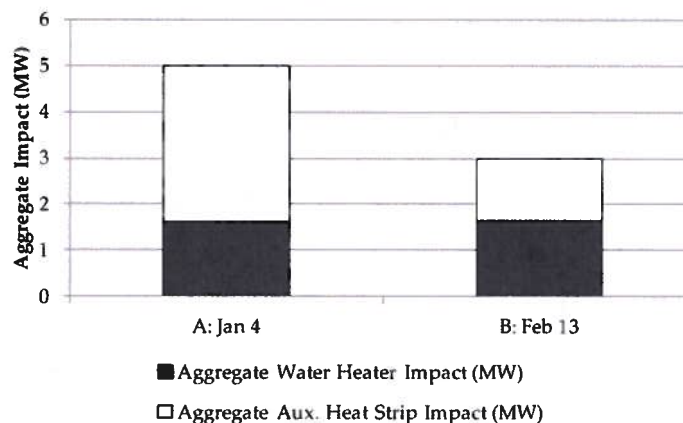
4.1.3 Program Aggregate Historical Impacts

As with the summer program, it is possible to extend the evaluation team's estimates of impacts per EM&V household to the entire program. This is accomplished by simply multiplying the per household impacts shown above to the total number of program participants for each of the two events experienced by non-EM&V households¹⁷. Note that, as with summer impacts this calculation implicitly assumes that the EM&V households are an accurate reflection of the distribution of households in the overall program population. Likewise it must implicitly be assumed that the average responsiveness rate of heat strips in the general program population is the same as in the EM&V population for each event.

Figure 17 shows the estimated aggregate impact for the two winter events to which the general program population was subject. Note that although the per-household impact of water heater curtailment was greater for Event A than Event B, program population growth between the two events mean that the aggregate impact of water heater curtailment was greater on February 13th than on January 4th.

¹⁷ Winter program population numbers may be found in Table 3, above.

Figure 17: Estimated Aggregate Impacts, Winter 2012



Source: Navigant Logger Data and Analysis

4.1.4 Energy Conservation

The driving purpose of a demand response program is to reduce system peak demand and thus allow for investments in generation and infrastructure to be postponed – it is the capacity provided by such programs that provides program value. Typically, evaluations of direct load control demand response do not even estimate conservation impacts because they are so trivial. The effects of snapback (where curtailed demand is “made up” in the period following curtailment) and the fact that there are typically not more than a few events per season, each only a few hours mean that conservation impacts – where they exist – will be very small.

For completeness, however, the evaluation team has calculated the average energy conservation achieved in the winter of 2012 per hour of event curtailment, by device controlled for each event. These impacts are presented in Table 12

Table 12: Winter Energy Savings (kWh)¹⁸ per Hour of Curtailment, by Device Controlled and Event

Event	Water Heaters	Aux. Heat Strips
A	0.08	0.66
B	0.08	0.21
C	0.05	0.16
D	0.06	0.00
E	0.05	0.06
Average	0.06	0.22

Source: Navigant Logger Data and Analysis

¹⁸ Note that in fact the calculated energy savings on event D is -0.01 kWh. This would suggest that curtailment on that event resulted in a miniscule increase in energy consumption. This nonsensical result is simply the result the small sample size of completely and partially responsive devices on that day. The evaluation team estimates therefore that there was no significant energy impact on that event day.

Average energy savings per hour were calculated by taking the total energy reduction estimated during the curtailment period, less the energy increase due to snapback¹⁹, divided by the number of hours of curtailment for each event.

4.2 Forecast Program Capability

An important component of the evaluation team's task in estimating the impacts of curtailment events was to not just estimate the impacts of the historical events (those discussed in the previous sub-section), but to make a forecast of PEC's DR capability at a variety of different temperatures. It is this forecast of capability that provides the truest estimate of a given DR program's value as a system resource, since it provides PEC staff with the knowledge of how much of a demand reduction the program may be counted on to deliver in true system peak conditions. This is also why it is the forecast of DR capability²⁰ that should be used to calculate the benefits for any cost-benefit ratio test (e.g., total resource cost test or TRC).

The reader should note that the forecast capabilities below represent the average demand reduction that could be expected over a single event, and not at a single hour or fifteen minute interval. The parameter estimates and other figures required to reproduce these lines for any given fifteen minute interval (in which an event was actually called) are provided in 5.2Appendix H at the end of this report. Using the numbers provided in 5.2Appendix H the reader will be able to reproduce a capability line only for those periods in which a 2012 winter event was actually called (i.e., no capability could be forecast for an event earlier than 6am or later than 9:30 am).

The forecast capabilities are presented in the two sub-sections below for the two different types of device controlled.

4.2.1 Forecast Water Heater Curtailment Capability

This sub-section presents the forecast DR capability, in terms of potential average per household kW impact, for water heater curtailment under a variety of different weather conditions.

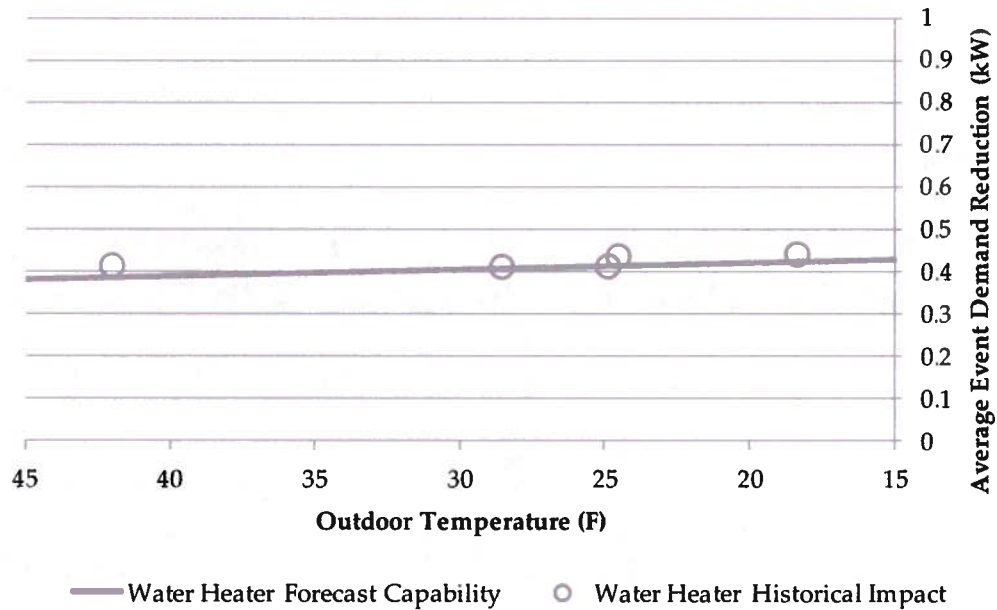
As noted above, in the discussion of the estimated historical impacts, the demand reduction impact of water heaters is relatively insensitive to changes in outdoor temperature – even on very cold days, the average per household impact of water heater curtailment is unlikely to much exceed 0.4 kW. Likewise, even on very warm days it appears unlikely that the average household impact will fall much below 0.4 kW.

This is illustrated in Figure 18 below. The line corresponds to the forecast average per-household DR capability of water heaters between 45 and 15 degrees Fahrenheit and the circles indicate the temperature/average impact pairs of the five historical curtailment events in 2012.

¹⁹ In this case snapback energy increases were calculated as the estimated snapback impacts greater than zero that were estimated over the number of hours following the event equal two-thirds of the number of hours of the event itself.

²⁰ In some jurisdictions this is sometimes referred to as an "ex ante" estimate of DR impacts. See for example the 2009 and 2010 evaluations of the Ontario Power Authority's *peaksaver*® program, a residential and small business residential direct load control program: <http://www.powerauthority.on.ca/evaluation-measurement-and-verification/evaluation-reports>.

Figure 18: Average Water Heater Forecast Capability and Historical Impacts per Household



Source: Navigant Analysis

4.2.1 Forecast Heat Pump Auxiliary Heat Strip Capability

This sub-section presents the forecast DR capability, in terms of potential average per household kW impact, for auxiliary heat strip curtailment under a variety of different weather conditions assuming the same proportion of non-responsive devices as observed in 2012 as well as under some scenarios assuming an improvement in the non-response rate.

As noted above, and discussed in greater detail in Appendix D, many auxiliary heat strips did not respond to, or only partially responded to, PEC's curtailment signal. Although, for conservatism, the evaluation team's principal forecast of auxiliary heat strip DR capability assumes that the current response rates will not change, the team felt it prudent to also present the forecast capability of auxiliary heat strips DR under two other scenarios. Each of these two additional scenarios assumes a progressive improvement in the device response rate due to technical or implementation improvements.

The evaluation team has noted that the number of completely responsive and partially responsive auxiliary heat strips was considerably lower for Event D (5th of March 2012) than for the other event days. This is due to the very warm temperatures observed on this day (42 degrees F on average during the event). Auxiliary heat strips are, for many heat pumps, simply not required for the efficient operation of heat pumps when the outdoor temperature is above 40 degrees F, and indeed the lower percentage of devices that were completely or partially responsive to the DR signal for Event D is due principally to an increase in the number of devices observed not to be in use (see Table 13, below). For this reason,

capabilities are forecast using two response rates: one for temperatures above 40 degrees F, and another for temperatures below 40 degrees F²¹.

Table 13, below provides the actual and assumed response rates used for forecasting DR capability. Note that the evaluation team has assumed that while technical and implementation innovations may be able to reduce the percentage of devices that do not respond at all to PEC's curtailment signal they will not affect the percentage of devices not in use.

Table 13: Historical and Assumed Response Rates for Forecast Capability

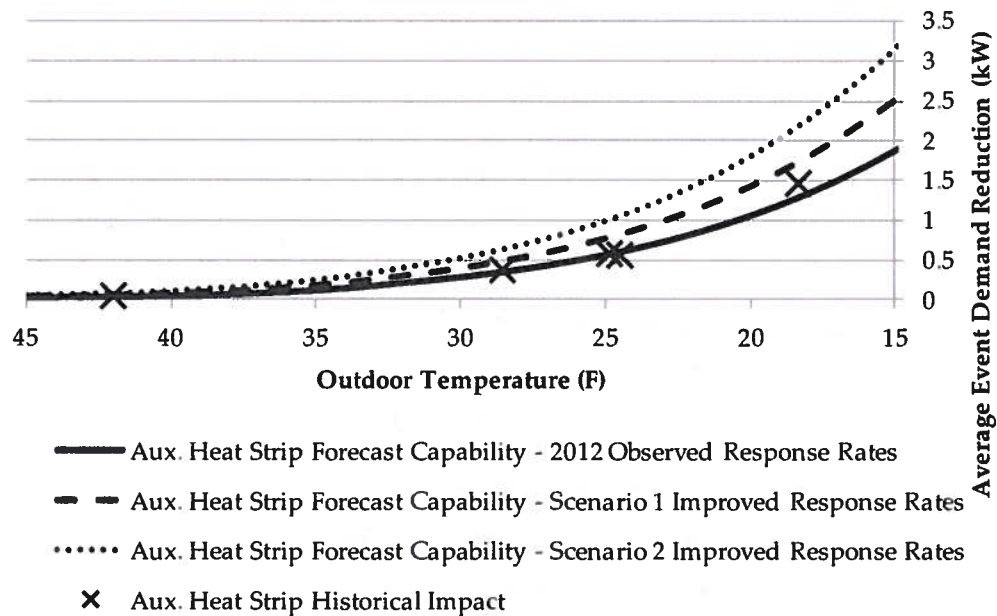
		Complete Response	Partial Response	No Response	Device Not In Use
2012 Responsiveness	>=40F	13%	8%	44%	36%
	<40F	23%	22%	41%	15%
Scenario 1	>=40F	25%	15%	24%	36%
	<40F	35%	25%	25%	15%
Scenario 2	>=40F	35%	20%	9%	36%
	<40F	50%	25%	10%	15%

Source: Navigant Analysis

The forecast DR capability under observed 2012 response rates, assumed Scenario 1 improvements to the response rate and assumed Scenario 2 improvements to the response rate are represented as the solid black line, the dashed black line and the dotted black line, respectively in Figure 19, below. The crosses indicate the temperature/average impact pairs of the five historical curtailment events in 2012.

²¹ Note that the evaluation team has assumed a gradual, rather than step, change from one response rate to the next as temperatures change. The gradual shift from >=40 degree response rates to <40F response rates occurs between temperatures of 42F and 33F.

Figure 19: Average Auxiliary Heat Strip Forecast Capability and Historical Impacts per Household



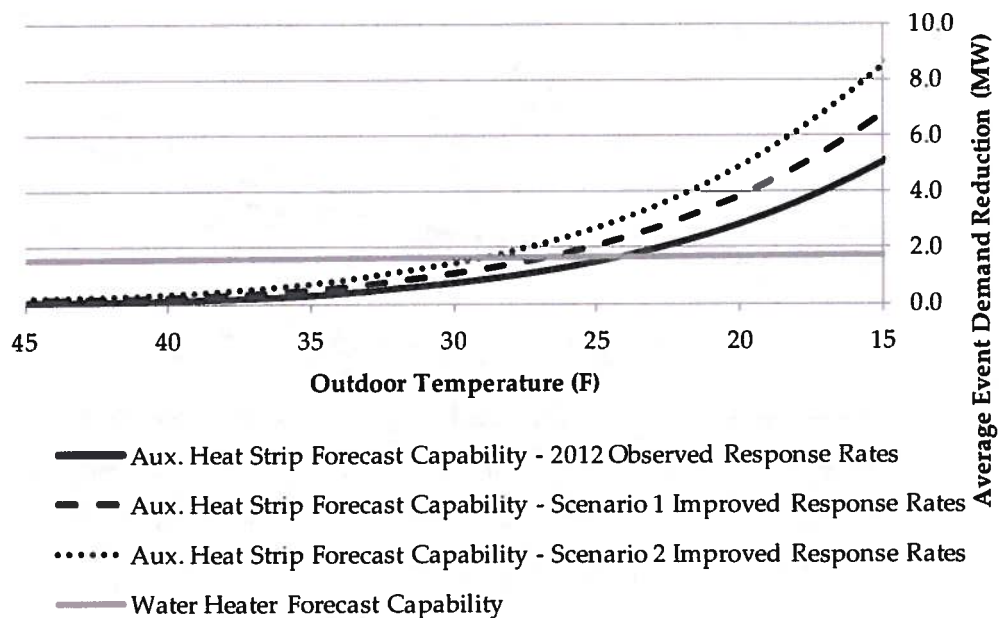
Source: Navigant Analysis

4.2.2 Program Aggregate Capability

As noted in the previous sub-section discussing historical impacts, a number of assumptions may be made to allow individual average impacts to be extrapolated out to the program population. To extrapolate forecast program capability an additional assumption regarding the level of program participation going forward must be assumed. To extrapolate aggregate capabilities, the evaluation team has conservatively assumed that the program population will stabilize at 2,700 auxiliary heat strip participants and 4,100 water heater participants.²² The forecast capabilities at a range of different average event temperatures are shown below in Figure 8. Note that for heat strips, as in the per-household capability section above, three scenarios are shown – one assuming that response rates will not change, and two assuming incremental improvements in the response rate, as shown in Table 13.

²² As of July 31, 2012, 2,614 auxiliary heat strip participants had joined the program and 4,055 water heater participants had joined the program.

Figure 20: Forecast EnergyWise Winter Program Capability With 4,100 Water Heater Participants and 2,700 Auxiliary Heat Strip Participants.



Source: Navigant Logger Data and Analysis

As may be seen from the figure above, should response rates be improved, the winter EnergyWise program could potentially provide PEC with nearly 10 MW of DR capability on very cold winter days.

5. Conclusions and Recommendations

Overall, the EnergyWise program had a very good summer in 2011, although there does remain room for improvement. There appears to have been steady growth in participation and curtailment events have delivered reliable and meaningful demand reductions when called.

The EnergyWise winter program in 2012 was not an unqualified success, although it did succeed in delivering substantial DR capacity at times of winter peak. PEC should be able in the future to greatly expand its winter DR capacity by improving the responsiveness of auxiliary heat strips to its control signal.

The high level of non response and partial response to PEC's control signal by auxiliary heat strips meant that the average DR impact of this side of the program was considerably lower than it could have been. That said, at nearly one and a half kW, the program's impact per household on the coldest day of the winter was still considerable.

5.1 Conclusions

5.1.1 Summer Program

The evaluation team found that summer event impacts were:

- As expected and more or less in line with what should be expected from a residential A/C curtailment program.
- Approximately proportional to the cycling strategy – for example, all else equal, an event using a 100% cycling strategy should deliver roughly twice as much demand reduction as a 50% cycling strategy.

The summer A/C snapback effect was investigated and it was concluded that:

- Snapback demand was relatively moderate but long-lasting.
- A major driver of the magnitude of snapback demand was the length of the curtailment period.

The second finding accords with what the evaluation team observed in its investigation of indoor temperature changes, the immediate cause of snapback. This analysis led the evaluation team to conclude that the length of the curtailment event had a greater impact (all else equal) on the change in indoor temperature than the cycling strategy used.

Summer indoor temperature increases were:

- On average, quite small, typically not more than one or two degrees Fahrenheit.
- For a significant minority of participants as much as three or four degrees Fahrenheit.

These relatively modest changes in temperature during summer events are likely responsible for the fact that nearly all surveyed participants are completely unaware of when events occur. Results of the summer survey also suggest that many of those that claim to have been aware that a summer event took place are simply mistaken – more placebo respondents claim to have been aware that a summer event took place than non-placebo respondents. Only a very small percentage (4%) of the summer survey respondents described their experience with the EnergyWise program as worse than they expected.

5.1.2 Winter Program

For the EnergyWise winter impacts, the evaluation team found that:

- Water heater impacts were, as expected, reliable and relatively insensitive to weather.
- That auxiliary heat strip impacts were highly sensitive to outdoor temperature, which was expected, but that impacts were less than would otherwise have been expected on very cold days, which was not expected.

Further investigation of the second point revealed that a very high percentage of auxiliary heat strips devices either did not respond to PEC's control signal or else only partially responded to it, resulting in a relatively low impact per household.

Analysis of the winter snapback impacts showed that:

- Both auxiliary heat strips and water heater snapback is a much shorter but sharper shock to the system than A/C snapback was in the summer.
- The average demand increase over the first hour beginning fifteen minutes after the end of the event was greater than the average demand reduction achieved during the event.

The effect noted in the second point was particularly pronounced for water heaters where snapback in the first hour beginning fifteen minutes after the end of the event was more than twice the average DR impact during the curtailment period.

Overall there is much cause for optimism for both the winter and summer EnergyWise programs. The evaluation team believes that PEC's most significant challenge in moving forward with the program is to fully understand and resolve issues surrounding the responsiveness of devices to the control signal. Recall that the evaluation team's estimate of the percentage of devices not responding to the control signal in the summer was only 11%, on average, the principal criterion used was quite conservative, and the true number of non-responsive A/C devices may be higher. More significantly, a very thorough analysis of auxiliary heat strip responsiveness in the winter found that on average, for the four coldest events, that over 40% of auxiliary heat strips failed to respond to a control signal and that over 20% only partially responded. Resolving this lack of auxiliary heat strip response may be the most important challenge facing the PEC winter program team.

5.2 Recommendations

The EM&V team recommends the following actions to improve program performance:

Recommendation Topic	Recommended Actions
Technical Issues	<ol style="list-style-type: none"> 1. Consider a thorough investigation into the cause or causes of device non-responsiveness. The evaluation found that 11% of A/C devices and over 40% of auxiliary heat strips do not respond to PEC's control signal for any given event. If the root cause of this non-responsiveness can be relatively easily addressed, PEC could potentially access additional DR capacity (in winter, considerable additional DR capacity) at very little incremental cost. Likewise, resolving the issue of auxiliary heat strips only partially responding to the PEC control signal could also add to PEC's winter DR capability even without incremental program recruitment.
System Planning and DR as a System Resource	<ol style="list-style-type: none"> 2. Use more aggressive cycling strategies in the summer to extract more value from the DR resource. The vast majority of cycling strategies used in the summer of 2011 were 50%, with a 100% strategy applied only for 30 minutes to the program population and the 65% and 75% strategies not applied at all. Given the apparent lack of awareness on the part of survey respondents to curtailment events, it seems likely that more aggressive cycling strategies could be used without significant program drop-outs as a result.
	<ol style="list-style-type: none"> 3. Increase coordination with system planning staff to determine the optimal summer curtailment event profile and test that profile. The most robust results of this evaluation relate to the impact of a 50% cycling strategy deployed for two to three hours in the mid-afternoon. In contrast only a single event was called for each of the 65%, 75% and 100% cycling strategies. If PEC would like in the future to implement these more aggressive cycling strategies, additional testing should be undertaken with careful controls to ensure robust capability estimates are possible. For example: four or more 100% events of the same length, at the same time of day, but a variety of different outdoor temperatures would allow PEC to more precisely isolate the effect of this strategy and more accurately estimate its DR capability. 4. Consider the impact of winter snapback when recruiting program participants. Given the very high level of snapback demand observed shortly after the end of winter events, program staff should consult with system planning staff to

Recommendation Topic	Recommended Actions
	determine the optimal number of participants in a given geographic area. In this way undesirable program impacts (such as overloaded circuits or peak migration) can be avoided.
Participant Recruitment and Retention	<p>5. Continue its practice of not advertising when curtailment events take place. Participants appear to be unaware of events, but when informed that an event did occur tend to ascribe feelings of discomfort to that event, even though likely that discomfort is the result of some unrelated issue – recall that only placebo participants indicated, when they were surveyed, that they had been “very uncomfortable” due to a (non-existent) curtailment event.</p>

Appendix A. Summer Device Responsiveness Analysis

As part of its evaluation of the EnergyWise program, the evaluation team estimated the number of A/C units within the EM&V sample that either did not respond to PEC's curtail signal, or simply were not running (and thus could not be curtailed) during events. Although there was no two-way communication to track the curtailment signal or device responsiveness, a careful examination of the A/C unit logger data, and some reasonable assumptions, have allowed the evaluation team to estimate the number of non responsive units.

The most significant findings of this analysis are:

- **On average, 11% of A/C units that were in use both prior to and following an event appear to have not responded to the PEC control signal.** This response rate was fairly consistent across events, fluctuating between 7% and 15% for any given event.
- **No device that was in use both prior to and following an event for more than three of the eleven events was assessed to have been non-responsive for every single event.** The non responsiveness of A/C devices cannot be ascribed solely to a small number of malfunctioning switches.
- **There does not appear to be a systematic pattern of device non-responsiveness, either over time or by geographic region of PEC's territory.**

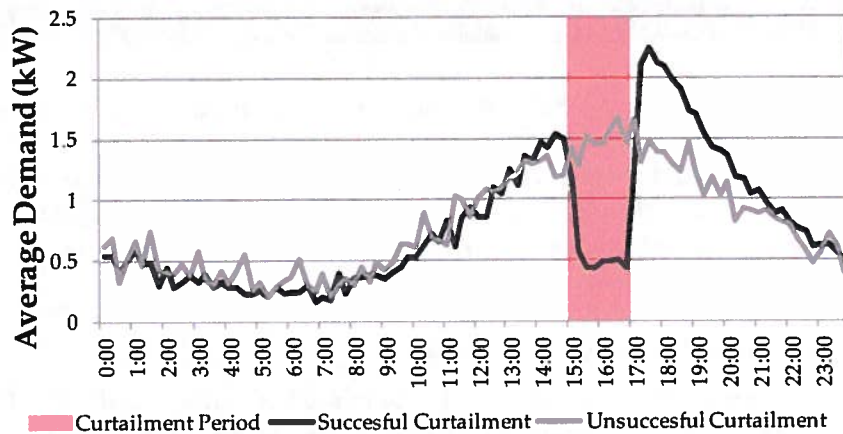
As noted above, these findings are predicated on the methods used and certain assumptions made by the evaluation team. A careful explanation of these assumptions and the method by which the evaluation team calculated the responsiveness rate follows below, preceded by some discussion as to the manner in which non responsive devices were distributed geographically and across time. The sensitivity of the evaluation team's method to changes in certain assumptions will also be discussed.

The evaluation team believes that its approach and assumptions are reasonable and have provided robust – if somewhat conservative – estimates of the device non response rate. The simplest demonstration of the reasonableness of the evaluation team's approach is a simple data plot based on the results obtained from this analysis.

The data plot in Figure 21 below shows the average demand on August 22nd of A/C units assessed to have responded to the PEC control signal and of A/C units assessed to not have responded to the signal.²³ The plot is consistent with expectations, that average demand will show a clear drop during a curtailment period if the control signal is received.

²³ Note that units that were deemed to be not in use during the event, in use during the event but not prior to the event, or in use during the event but not following the event, are not included in this plot.

Figure 21: Illustration of Reasonableness of Device Responsiveness Analysis Approach



Source: Navigant Logger Data and Analysis

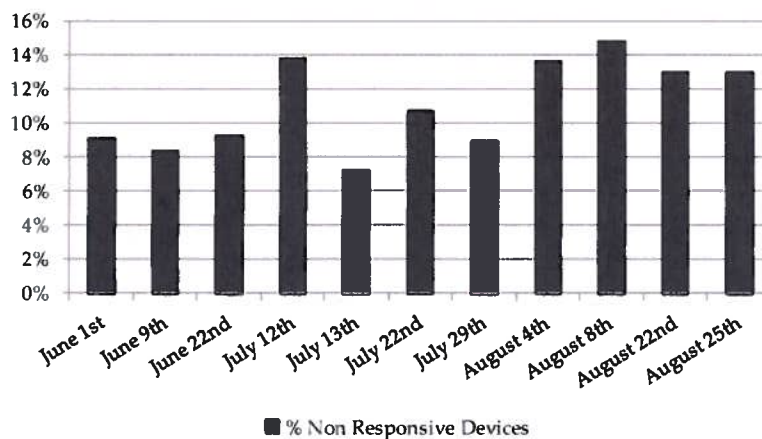
The remainder of this section is divided into four sub-sections:

1. **Distribution of Non Responsive Devices:** this sub-section provides summary statistics regarding non responsive devices by event and by PEC region.
2. **Method for Determining Device Responsiveness:** this sub-section provides a step-by-step guide to the method used by the evaluation team to estimate whether or not a given device had failed to respond to the curtailment signal on a given event day.
3. **Sensitivity of Approach:** this sub-section provides some sensitivity analysis – it shows what the estimated percent of non responsive devices would be as certain assumptions change.
4. **Choice of Threshold:** this sub-section discusses why the principal input assumption – a percentage threshold – was chosen by the evaluation team for this analysis.

A.1 Distribution of Non Responsive Devices

The non response rate does not appear to vary in a systematic way by event and no single device in use for more than three events was found to be non responsive to all events. This suggests that in most cases the underlying cause for devices not responding to the PEC control signal is something other than defective or poorly installed switches (see Figure 22, below).

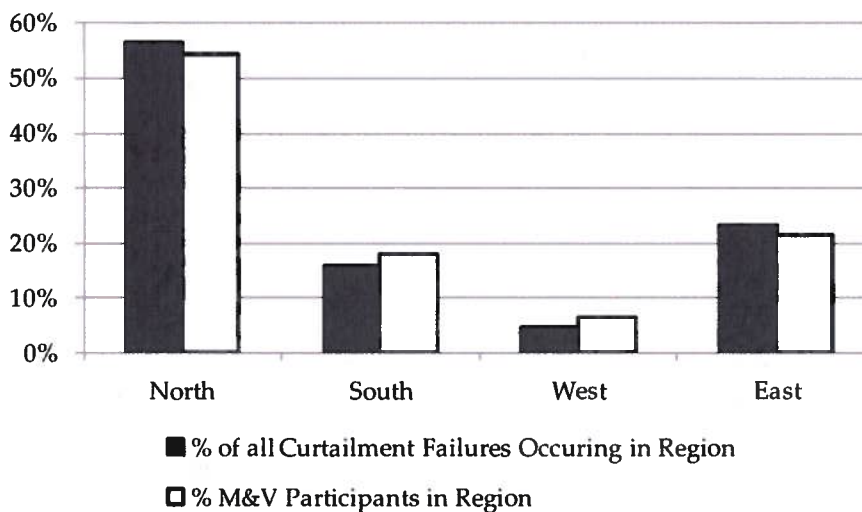
Figure 22: Distribution of Non-Responsive Devices Across Events



Source: Navigant Logger Data and Analysis

Likewise, there does not appear to be a systematic relationship between the region in which an A/C unit resides and the likelihood of its not responding to the control signal. Although PEC's northern region accounts for the highest percentage of non responsive devices it is also the region with the highest percentage of EM&V participants, as shown in Figure 23 below.

Figure 23: Distribution of EM&V Participants and Non Responsive Devices by PEC Region



Source: Navigant Logger Data and Analysis

A.2 Method for Determining Device Responsiveness

Unused A/C Units

The first step in the process of assessing device responsiveness was determining which A/C units were not in operation at all during the event (and thus would provide no curtailment if the signal was successful and the control device fully functioning). The evaluation team determined that if the average

demand logged for an A/C unit in the last hour prior to an event and in the first hour following an event was less than 0.25 kW, then it was likely that the unit was not in use during the curtailment period. A device determined not in use during the event by definition can be considered neither a responsive nor a non-responsive device.

Non-Responsive Devices

The following steps were used to determine if a device was non-responsive:

Step 1: Calculate the average demand for each A/C unit in the final hour prior to an event starting (the "prior hour") and for the hour following the first half hour of the event (the "event hour").

For example:

For the event on July 12th (3p.m. to 6p.m.) the difference between average demand from 2 p.m. to 3 p.m., and the average demand from 3:30 p.m. to 4:30 p.m., was calculated. The reason for using the average demand over the hour immediately following the first half hour of the event (as opposed to simply using the first hour of the event) is to militate against the possibility that curtailment is staggered across devices. Put another way: if some devices begin curtailing fifteen or twenty minutes into an event instead of at the instant the event begins, then assessing device responsiveness using the average demand in the first hour could result in the evaluation team assessing a device as non-responsive when in fact it may have responded to the control signal.

Note that in the case of the events on July 13th and August 25th, the event lasted only a single hour. In those cases, the "event hour" used was in fact the whole hour of the event.

Step 2: Calculate the percentage change in average demand from the "prior hour" to the "event hour".

Step 3: Compare this percentage change with a pre-determined threshold. If the calculated percentage change is less than the threshold, then curtailment is deemed to have failed.

The figures presented above were calculated based on a 0% threshold. That is, provided the average demand in the event hour was not greater than the average demand in the prior hour, curtailment was deemed to be successful. This is a quite conservative threshold in the sense that it is intended to minimize the number of devices that are incorrectly deemed to be non responsive. However, using this threshold also means that it is likely that some non-responsive devices were incorrectly assessed to have been responsive. Further discussion of this choice of threshold follows.

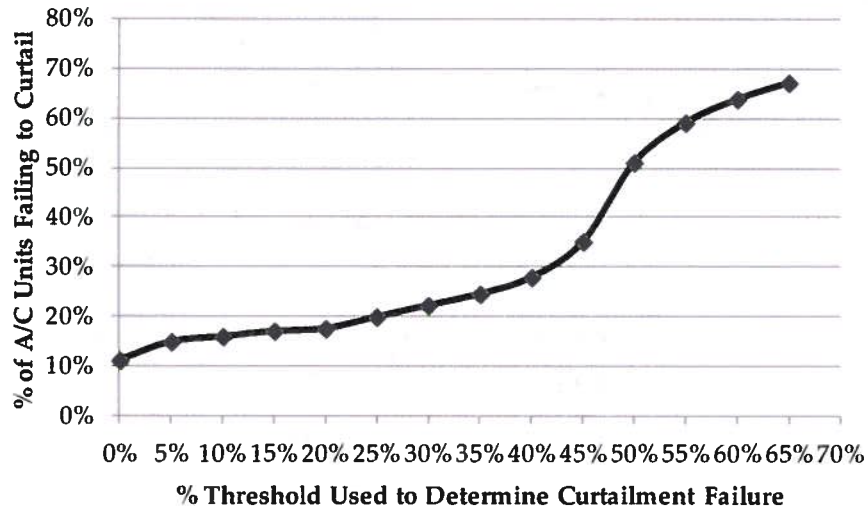
A.3 Sensitivity of Approach

The most important driver of the results presented above is the use of the 0% threshold. This is a very conservative threshold to use since even the least aggressive of the curtailment events used a 50% cycling strategy. Theoretically, a 50% event should produce a 50% reduction in average demand over a given event hour. To be conservative, and recognizing that a 50% cycling strategy may very likely result

in less than 50% curtailment – perhaps considerably less – the evaluation team chose to use a threshold of 0%.

To demonstrate the sensitivity of the evaluation team’s approach, the percent of devices that are non-responsive averaged across all events was calculated using a wide range of thresholds. The average percent of A/C units that were non responsive at a range of different threshold percentages is presented in Figure 24 below.

Figure 24: Sensitivity of % of Devices Deemed Non-Responsive to % Threshold Used

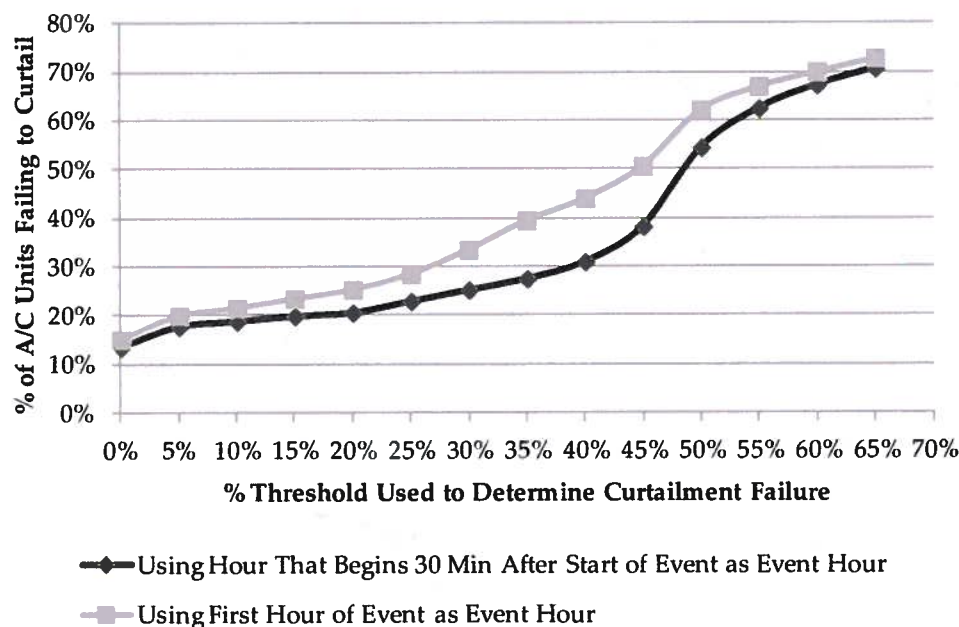


Source: Navigant Logger Data and Analysis

As noted above, the “event hour” used for comparison is in fact the hour following the first thirty minutes of an event (for events that were at least an hour and a half long). This was chosen to control for the fact that curtailment is typically staggered – not all devices begin curtailing at once. In the context of examining the sensitivity of the process used to determine which devices failed to curtail, it is worth examining the sensitivity of the results to this assumption.

In Figure 25, below, the sensitivity of the analysis to the threshold chosen is compared using two different event hours: the hour following the first thirty minutes of the event, and the first full hour of the event itself. The black line is the same as in Figure 24, above, and represents the sensitivity of the analysis in the case when the event hour used is the full hour that begins following the first thirty minutes of the event. The grey line represents the sensitivity of the analysis in the case when the event hour used is the first full hour of the event itself. Note that at every point in the graph the grey line is higher than the black line. This suggests that the evaluation team’s assumption regarding the staggering of curtailment was reasonably accurate.

Figure 25: Comparison of Sensitivity – Using Hour That Begins 30 Min After Start of Event as Event Hour vs. Using First Hour of Event as Event Hour



Source: Navigant Logger Data and Analysis

In addition to requiring that demand in the event hour be less than demand in the prior hour by some amount (i.e. the threshold), a more stringent requirement would ALSO require that demand in the first hour following an event (the “snapback hour”) be greater than the average demand in the final hour of the event (the “final event hour”). This more stringent requirement means that a device cannot be deemed to have successfully curtailed unless there is some sign of snapback.

As noted earlier, the evaluation team used a 0% threshold for comparing the prior hour and the event hour, a threshold believed to be reasonable and conservative. Imposing a 0% threshold for comparing the final event hour to the snapback hour – that is, requiring that demand in the first hour following an event be greater than demand in the final hour of the event – has relatively little impact on the percentage of devices deemed to have responded to the control signal. Imposing the 0% snapback threshold increases the percentage of non responsive devices by four points, raising the total percentage of non-responsive devices to 15% instead of 11%. At higher percentage thresholds when comparing the prior and event hour, this difference disappears, and at lower levels, it is likely that some of what is being observed is simply the fact that the end of an event is not instantaneous – not all devices finish curtailing at the same time. Given the above, the evaluation team decided not to use this additional condition in determining device responsiveness.

A.4 Choice of Threshold

As noted previously, there exists no definite way of knowing precisely which devices are successfully curtailing or not – there is no two-way communication between each switch and the event controller monitoring device responsiveness. Thus, after examining the evidence (including a very large number of

data plots as may be seen in Appendix I, below), the evaluation team used its professional opinion and settled on the approach and threshold outlined above.

Initially, a threshold of 25% was considered. Although in theory, with an adaptive algorithm and with the least aggressive cycling strategy deployed being a 50% strategy, demand during the curtailment event should be roughly half of what it was immediately prior to the event, on average. Acknowledging that theoretical demand reductions resulting from engineering analyses tend to exceed the actual observed demand reductions, the evaluation team believed that a 25% threshold offered a reasonable balance between an aggressive threshold (which would exaggerate the number of failed devices) and a conservative one (which could possibly deem some devices to have successfully curtailed when in fact they failed).

Extensive examination of data plots of average levels of demand and temperature of responsive and non responsive devices at three different threshold levels (0%, 15% and 25%) for each of the curtailment events as well as careful consideration of this analysis' loss function (see below) led the evaluation team to conclude that a 0% threshold was the most sensible threshold to use.

Loss Function Considerations

A loss function is one way economists take into account estimation uncertainty when determining the most profitable course of action, given some previously estimated probabilities. The car seat belt provides a reasonable example: while the probability of being in a car accident for any given trip in a car is relatively small, the consequences of being in such an accident and *not* having a seat belt on could be potentially very dire. Although we acknowledge the probability of an accident is low, we choose to wear the seat belt anyway, even though it may cause some discomfort.

In this case, by setting the threshold for deeming a curtailment successful at 0%, the evaluation team is attempting to minimize PEC's loss function. The purpose of isolating non-working devices through the data is to allow PEC to investigate non responsive devices so that for future deployments and events, the number of non responsive devices can be minimized. Recognizing that PEC's resources are not unlimited and that such investigations (which require the deployment of technicians) are costly, it makes sense to limit such investigations only to devices that the evaluation team is certain – or as nearly certain as is possible, given the circumstances – have been non responsive.

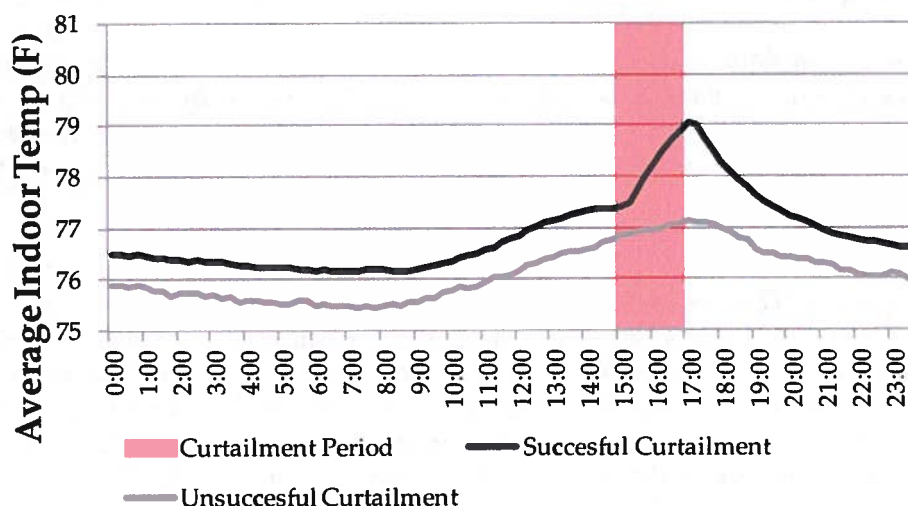
Examination of Data Plots

Driven by the consideration that whatever threshold was chosen, it should minimize the number of "false positives" (i.e. responsive devices deemed to have been non responsive), the evaluation team carried out an extensive visual analysis of the data. This consisted of carefully comparing plots of average indoor temperature and demand for units deemed to have failed to curtail to those of units deemed to have successfully curtailed using three different threshold values: 0%, 15% and 25%. All of these plots, as well as important summary statistics may be found in Appendix I.

Given the notoriously "noisy" nature of demand data, particularly in small samples, the evaluation team believes that false positives are most easily detected by observing the change in indoor temperature data rather than the demand data. Plots of demand data as well as of temperature data may be found in Appendix I.

Although curtailment seems to provoke a relatively small absolute change in the temperature level (typically one to two degrees Fahrenheit) it does significantly and visibly change the shape of the indoor temperature curve, as shown in Figure 26 below. Note that the black line (successfully curtailed devices) rises steeply in the hours of the event compared to the grey line, and then fall steeply at a decreasing rate (i.e., is concave) following the end of the event. The grey line, by contrast, follows its peak with a gentle convex (i.e. bowed upward not downward) decline. Note also that the temperature change lags behind the moment the event begins slightly, due to the fact that individual units are not all activated at the same time.

Figure 26: Indoor Temperature, August 22nd, 2011 Using 0% Threshold

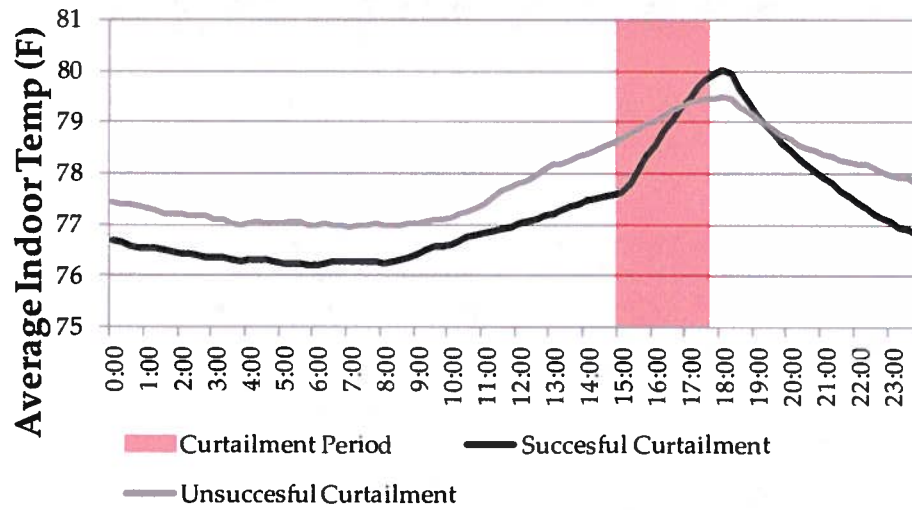


Source: Navigant Logger Data and Analysis

Indoor temperature change, in particular a relatively sharp peak in temperature immediately following the end of an event, appears to be a reasonable method by which to identify whether or not there exist any false positives at a given percentage threshold.

A couple of examples at different (i.e., higher than 0%) threshold levels may serve to further illustrate why the evaluation team has chosen to use the 0% threshold. First, consider Figure 27, below. Note the shape of the grey line (the load profile of those devices deemed to have unsuccessfully curtailed). Although not so distinct as may be observed in the black line, the grey line appears to have a slight convexity beginning at exactly the same point as the black line. Although not conclusive, a comparison with the indoor temperature profile for the same day using the 0% threshold (which may be found in Appendix I.) shows that at this higher threshold the temperature profile has much more of the “shark-fin” shape associated with curtailment. This suggests that using the 15% threshold results in some false positives.

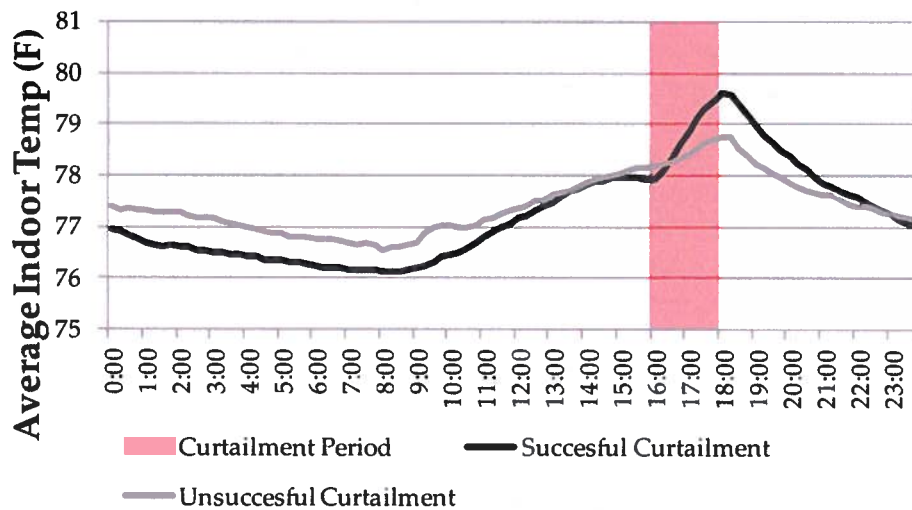
Figure 27: Indoor Temperature, July 12th, 2011 Using 15% Threshold



Source: Navigant Logger Data and Analysis

The effect becomes even starker when using a 25% threshold, as shown in Figure 28, below. Note the distinctive shark-fin shape of the grey line indicating that a number of responsive devices have been erroneously included in the group assessed to be non-responsive. This may be compared in Appendix I to the gentle "hump" peak temperature observed for the same day when a 0% threshold is applied.

Figure 28: Indoor Temperature, June 1, 2011, Using 25% Threshold



Source: Navigant Logger Data and Analysis

Given the assumed loss function and the variation of indoor temperature in the sample homes, the evaluation team concluded that 0% is the most appropriate threshold for determining which devices successfully curtailed and which devices did not.

Appendix B. Summer Indoor Temperature Impacts

All EM&V participating A/C units collected indoor temperature data, in addition to load data. This section contains the evaluation team's analysis of this data. The evaluation team's principal findings with regard to indoor temperature data were that:

- **On average the increase in indoor temperatures during summer events was relatively small (between one and two degrees Fahrenheit).** A significant minority (over 20%) of thermostats, however, recorded changes in indoor temperature over the course of events as high as three or four degrees Fahrenheit.
- **The most significant factor impacting the change in indoor temperature during summer events over which PEC has control appears to be the length of the curtailment event.** The impact of the curtailment strategy on indoor temperature appears to be secondary to the impact of the length of the period.

Indoor temperature during events and the impact of the length of the event and the aggressiveness of the curtailment strategy employed on that indoor temperature can provide important information for program managers hoping to maintain or improve program participation. In terms of the program manager's choice of curtailment strategy (50% event, 75% event, etc.) and the length of the event to be called he or she is faced with a problem of constrained optimization; he or she would like to maximize the benefits (high demand impacts lasting several hours) while minimizing the number of participants deciding to exit the program due to uncomfortably high indoor temperatures during events.

To solve such a problem analytically would require far more data than is currently available regarding the relationship between changes in indoor temperature and personal comfort on the one hand and changes in comfort and the willingness to put in the effort to leave the program on the other. A thorough examination of the degree to which different types of events affect indoor temperature, however, coupled with the findings of an examination of participant perceptions of the program (found below in Appendix C), can do much to inform the judgment of program managers and help them decide just how to deploy curtailment events for optimal effect.

This section of the report, and Appendix J, provides an analysis of the temperature changes observed in the EM&V homes for the various events.

This section is split into the following sub-sections:

1. **Methods and Data Used:** this sub-section contains a discussion of the methods and data used by the evaluation team for this analysis.
2. **Distribution of Change in Indoor Temperature:** this sub-section discusses how the changes in indoor temperature were distributed amongst households.
3. **Drivers of Indoor Temperature Change:** this sub-section discusses the different drivers of indoor temperature change – event length, cycling strategy and outdoor temperature – and their relative impact on that temperature change.

B.1 Methods and Data Used for Indoor Temperature Analysis

The reader should assume that, unless stated otherwise, all discussion of indoor temperature impacts are in reference to only responsive²⁴ individual A/C units. This means that in cases where a single participant has two connected A/C units, the recorded temperatures from both thermostats in a single household are recorded as two individual observations in the figures and tables that follow.

The reader should also be aware that there exist fewer useable indoor temperature data for the EM&V sample than demand data. This is due simply to the fact that the temperature-gathering component of the data loggers failed more frequently than the demand recording component. Thus, for example, while there were 91 units for the June 1st event that were deemed to have been responsive to the PEC control signal under the 0% threshold described in Appendix A, there exist reliable indoor temperature data for only 88 of these units.

The analysis which follows focuses on the change in the indoor temperature recorded by each A/C unit's thermostat observed during an event. While it is possible that not all of the observed change in temperature is due to the curtailment event²⁵ it seems likely that the majority of the change observed during (or immediately following) an event *is* due to that event. The changes in temperature presented are calculated as the difference between the highest observed temperature during or in the hour following an event and the average indoor temperature in the hour prior to the event. The range from which the highest temperature may be drawn (to calculate the temperature change) includes the hour following the event to account for the fact that events are staggered (it is possible that an individual unit may still be curtailing shortly after the event) and for the observation in Appendix A, above, and in other studies of this nature, that indoor temperature lags A/C curtailment somewhat.

B.2 Distribution of Change in Indoor Temperatures

One thing becomes clear when examining the distribution of indoor temperature changes amongst thermostats: despite relatively low average changes in temperature over the whole sample, there is a substantial minority of units which is subjected to quite high changes in temperature.

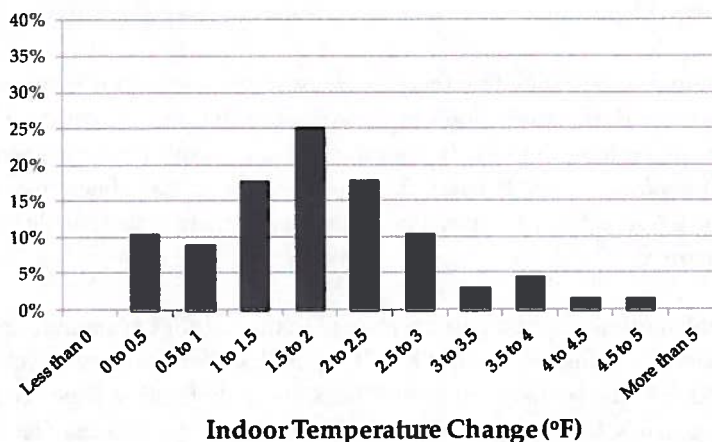
Recall Figure 26, above, which showed the average indoor temperature of successfully curtailing units on August 22nd, a two hour 75% event on a day on which the average system temperature at the time of instantaneous system peak was 90 degrees F. Examining the peak of that curve and its level immediately preceding the event, it may be seen that the event appears to have resulted in an approximately 1.8 degree increase in indoor temperature. While this is relatively modest, an examination of how the changes in temperature were distributed amongst households reveals that over 20% of those devices that successfully curtailed and for which temperature data existed, experienced an increase in

²⁴ As defined above in 5.2 Appendix A of this report. The reader should also note that the group of units examined does not include units for which the determination of successful curtailment is ambiguous – that is, units that were in operation prior to the event but not following it, or for units in operation following the event, but not prior to it. The group of successfully curtailed units does not include units that were not in operation both before and after the event.

²⁵ For e.g., if a day was so hot that the A/C unit could not maintain the set-point temperature then the indoor temperature would rise even if the unit had not been curtailed.

temperature of over 2.5 degrees F, and that 3% of those thermostats experienced increases in temperature of over 4 degrees – see Figure 29, below.

**Figure 29: Distribution of Change in Indoor Temperature – Aug. 22.
Successful Curtailments Only, 75% Event, 2 hours, Outdoor Temperature: 90F**



Source: Navigant Logger Data and Analysis

Frequency distributions similar to that shown in Figure 29 for all eleven of the EM&V events for which data exist are included in Appendix J, below. Program managers are encouraged to examine these carefully, bearing in mind the different cycling strategies used on each day, the length of the curtailment event and the outdoor temperature at the time of the event.

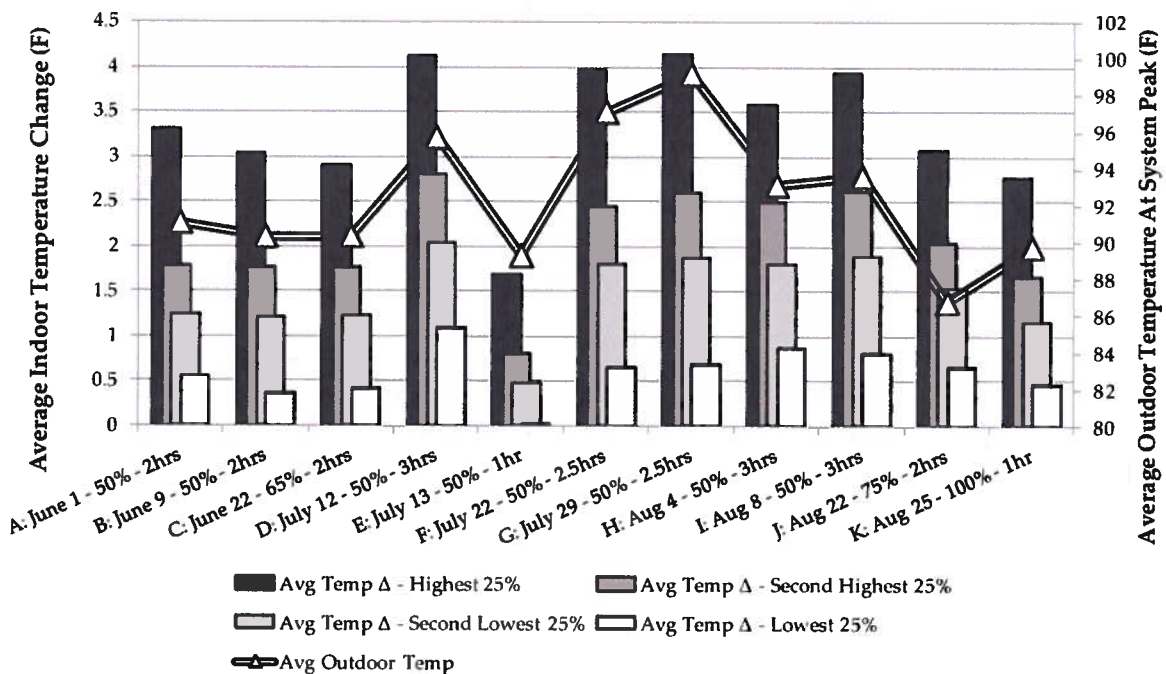
These frequency distributions are of most interest when compared to one another and can provide considerable insight. To compare all eleven frequency distributions to one another, however, is cumbersome and inefficient, and a good high level understanding of the relationships at work may be developed by examining this data in somewhat summarized form, as shown in Figure 30, below. Figure 30 is particularly dense with information, so it is important that the reader fully understand its individual components prior to reading the evaluation team's analysis of what it suggests.

This chart shows:

- **The black, dark grey, light grey and white columns (left axis).** These show the average change in indoor temperature for the four interquartile ranges observed amongst successfully curtailing A/C unit thermostats for each event. More specifically:
 - **Black column.** The average temperature change experienced by the 25% of successfully curtailing thermostats that experienced the largest increases in temperature during, or immediately following, a curtailment event.
 - **Dark grey column.** The average temperature change experienced by the 25% of successfully curtailing thermostats that experienced the second largest increases in temperature during, or immediately following, a curtailment event.

- **Light grey column.** The average temperature change experienced by the 25% of successfully curtailing thermostats that experienced the second smallest increases in temperature during, or immediately following, a curtailment event.
- **White column** The average temperature change experienced by the 25% of successfully curtailing thermostats that experienced the smallest increases in temperature during, or immediately following, a curtailment event
- **Double black line with white triangle markers (right axis).** This series indicates the average outdoor temperature to which A/C units included in this sample were exposed on each event.
- **Horizontal axis.** This provides salient details regarding each event. For example, directly below the first set of columns from the left side of the chart it says "A: June 1 - 50% - 2hrs". This indicates that the event happened on June 1st, that the curtailment strategy used was 50% cycling, and that the event lasted for two hours. The letter that precedes the axis label – "A" in this case – is simply included to allow for easy reference when discussing and comparing different events (i.e., "Event A" as opposed to "the June 1 event").

Figure 30: Comparison of Indoor Temperature Interquartile Ranges Across Events



Source: PEC EW Control Event Tracking Report and Navigant Logger Data and Analysis

B.3 Drivers of Indoor Temperature Change

Figure 30 provides an excellent high-level illustration of how the change in indoor temperature in each of the interquartile ranges changes from event to event, and illustrates the various dimensions which may affect that temperature change.

What Figure 30 cannot provide, however, is a reasonably robust causal relationship. By comparing Event E and Event K (the only two one-hour events), one can infer that the curtailment strategy appears to be an important driver of indoor temperature. But how important is this when compared with the length of the curtailment event?

To better quantify the relationship between the change in indoor temperature and what the evaluation team believes to be the principal driving factors, further regression analysis was used. Algebraically, the model estimated was the following:

$$\Delta Temp_{i,t} = \beta_0 + \beta_1 Otemp_{i,t} + \beta_2 Length_t + \beta_3 Strategy_t + errors$$

Where:

- $\Delta Temp_{i,t}$ = The change in indoor temperature observed by the thermostat i during event t , where t counts each of the 11 events for which data exists.
- $Otemp_{i,t}$ = The average outdoor temperature to which thermostat i was exposed during event t and the hour immediately following event t .
- $Length_t$ = The length of event t , in hours.
- $Strategy_t$ = The curtailment strategy employed for event t (e.g., 50% event, 65% event, etc.)

The parameter estimates, their standard errors, t-statistics and p-values are shown below:

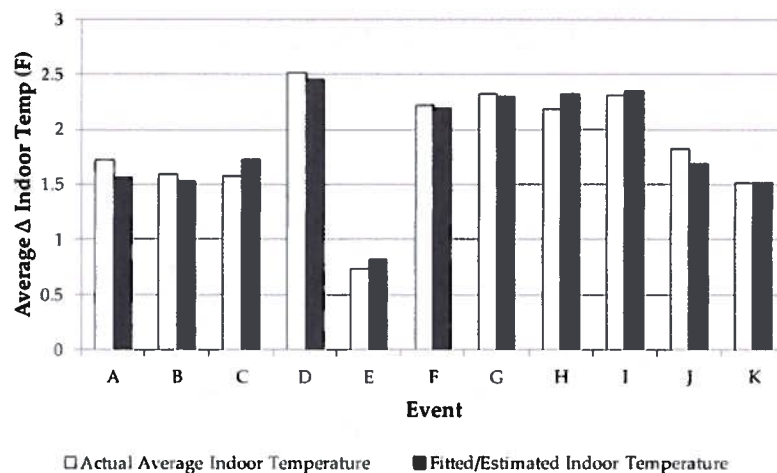
Table 14: Indoor Temperature Regression Output

	Avg Outdoor Temperature	Length of Event	Curtailment Strategy
Parameter Estimate	0.0499	0.6570	1.3536
SE	0.0082	0.0690	0.3032
t-statistic	6.1114	9.5252	4.4642
Pr > t 	0.0001	0.0001	0.0001

Source: Navigant Logger Data and Analysis

To test the reasonableness of the estimates, the evaluation team compared the average observed temperature impact observed for each event (across all the thermostats that were responsive to the control signal) with the fitted values implied by the parameter estimates obtained in Table 14 and the corresponding variable values. This comparison is shown in Figure 31, below.

Figure 31: Reasonableness Test – Drivers of Indoor Temperature Change



Source: Navigant Logger Data and Analysis

Note how close the white and black bars are to one another in Figure 31. Clearly the estimated parameters are doing a very good job of predicting how the various drivers will affect the change in indoor temperature within the sample.²⁶

These parameter estimates tell us a number of interesting things about how indoor temperature changes during events, and how the various drivers of that change affect it. Firstly, it is clear that outdoor temperature (represented by the variable *Otemp_{it}*) has the most significant impact on indoor temperature – this is to be expected. Secondly, although the parameter estimate on the variable capturing the curtailment strategy is the largest (and more than twice as big as the second-largest parameter estimated) it must be remembered that the range of curtailment strategy only extends as high as 1 (100%), whereas curtailment events lasted as long as three hours.

Thus, the estimated parameters suggest that although changing a curtailment strategy from 50% to 100% would result in an increase in indoor temperature of approximately 0.68 degrees²⁷, increasing the length of an event from one to three hours would, all else equal, result in an increase in indoor temperature of 1.31 degrees.²⁸ Given the impact of indoor temperature on participant comfort, this suggests that if PEC can accurately target individual hours (as opposed to three hour blocks) for which the DR resource is required, it can deploy a very aggressive cycling strategy without alienating too many participants.

²⁶ The evaluation team would note that while these estimates are highly suggestive as to what might occur for future events (given the outdoor temperature at the time, the length of the event and the curtailment strategy employed), the reader should be cautious about depending too much on their forecasting accuracy. Within the sample there are, after all only a single 65%, 75% and 100% event.

²⁷ An incremental 50% x 1.3536 (the parameter estimate) = 0.68 degrees F.

²⁸ 2 hours x 0.657 (parameter estimate) = 1.31 F

Appendix C. Summer Participant Perceptions Analysis

This section presents the findings of the evaluation team's analysis of four identical surveys conducted in August 2011 of EnergyWise participants. Respondents to each survey may be divided into two groups: EM&V participants and non-EM&V participants. EM&V participants are those participants for whom the evaluation team has A/C logger data used to estimate impacts. Non-EM&V participants are those participants in the program for whom the evaluation team has no logger data.

Three of the surveys were conducted very shortly – a day or two – following a curtailment event to which EM&V participants were subject. The fourth survey was conducted on the 11th and 12th of August informing participants that an event had occurred that day and (as with the other surveys) asking for participants' opinions and perceptions of comfort during the event. This "event" was however a placebo; no curtailment event was called for August 10th.

Non-EM&V participants were in fact subjected to surveys regarding two placebo events. As well as the August 10th placebo event that applied to both EM&V and non-EM&V participants, non-EM&V participants were surveyed for their perceptions of comfort during the August 22nd curtailment event which in fact applied only to EM&V participants, meaning that effectively non-EM&V participants were subject to two placebo events.

The evaluation team's principal findings of the analysis of participant perception were:

- **Participants are generally unaware of curtailment events when they happen.** Most survey respondents indicated, when asked, that they had not been aware that an event had occurred in the previous few days. More placebo respondents indicated that they were aware an event had occurred recently (when one hadn't) than non-placebo respondents (who were subject to real events).
- **Only about 10% of survey respondents that had experienced a real (non-placebo) event indicated that they were "much less comfortable" than normal.** Most indicated they were "somewhat less comfortable" than normal and none indicated that they were "very uncomfortable". Interestingly, more non-placebo respondents than placebo respondents characterized their comfort during the event as: "the same as a normal afternoon".
- **Participants are generally satisfied with the EnergyWise program.** Over half of the respondents indicated that their experience with the program was "about what I expected" and 15% indicated that their experience with the program was "better than I expected". Only 4% indicated that their experience with the program was "worse than I expected". Combined with PEC's finding of an annual participant attrition rate of approximately 2% this suggests that generally, once recruited, participants are likely to be retained in the program.

The number of survey respondents for each event is shown below in Table 15. Cells highlighted in red indicate a placebo event for the given sub-sample.

Table 15: Survey Participation and Placebo Events

	EM&V Sample	Non EM&V Sample
8-Aug-11	12	25
10-Aug-11	11	25
22-Aug-11	11	25
25-Aug-11	11	25
Number Surveyed About ACTUAL Event	34	50
Number Surveyed About PLACEBO Event	11	50
Total Surveyed:	45	100

 = Placebo Event (no curtailment)

Source: Survey Data and PEC EW Control Event Tracking Report

This section of the report is divided into three different sub-sections each of which analyzes a different aspect of participant perceptions. These are:

1. **Participants' awareness of events:** to what degree were participants aware that an event had taken place?
2. **Participants' comfort during events:** how comfortable were participants that were aware an event had taken place.
3. **Participants' general satisfaction with the program:** how happy or unhappy are participants with the program?

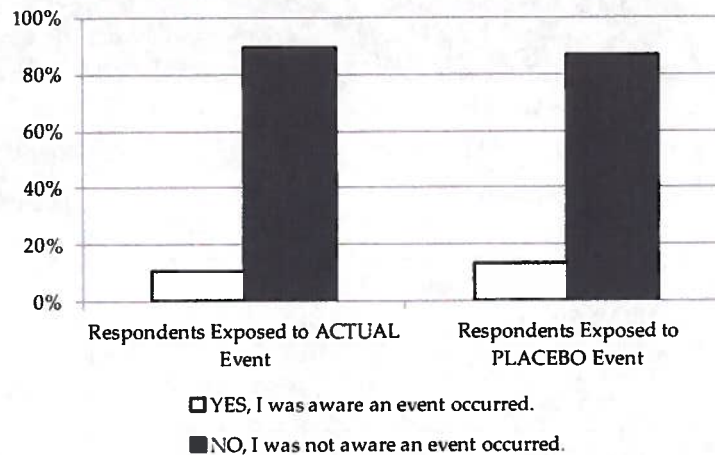
C.1 Awareness of Event

The principal purpose of the surveys was to determine the degree to which participants both noticed and were made uncomfortable (due to a change in indoor temperature) by curtailment events. The surveys allow for the exploration of some subtleties, but the most basic question the survey was designed to answer – and one which was, in the surveys put directly to respondents – is simply:

“Were you aware that an air conditioning cycling event had occurred?”

The distribution of answers to this question by respondents asked about actual curtailment events and those asked about placebo events is shown below in Figure 32. As may be seen, not only were the vast majority of respondents unaware that an event had occurred, but a higher proportion of the respondents exposed to a *placebo* event than an actual claimed to have been aware that an event had taken place.

Figure 32: Responses to “Were you aware that an... event had occurred...?”



Source: Survey Data

What may be understood in this case is that it is most likely that many – if not all – of the survey respondents were simply responding to the survey as if it were a test with right or wrong answers and “gaming” the survey²⁹.

C.2 Comfort During Event

Awareness of a curtailment event is certainly the most important barometer of the impact on customer comfort the event had – clearly if a participant did not notice an event then its impact on his or her comfort must be trivial. In this case, however, it is not the only measure of the impact on the participant. Each respondent, regardless of whether he or she had been aware of the event, was asked to characterize his or her level of comfort during the event.

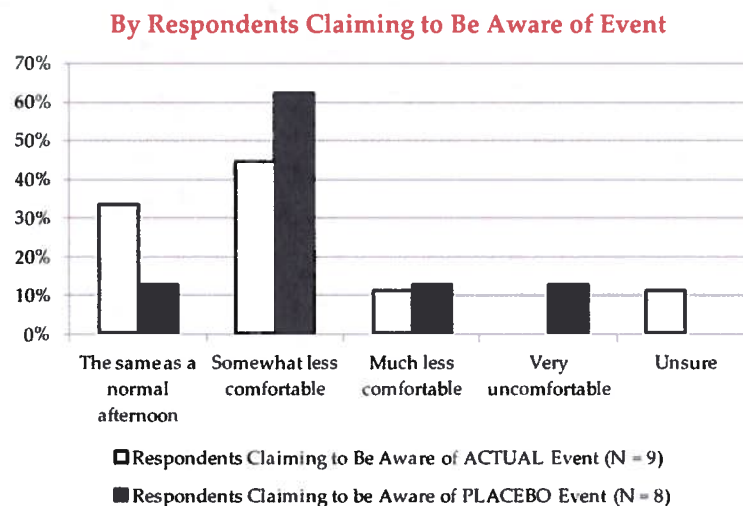
Although all respondents – regardless of whether they claim to have been aware or not of the curtailment event – were asked about their comfort level during the event, for PEC’s purposes, the responses of those that were not aware of the event are irrelevant. A major concern of summer DR programs is that curtailments that are too aggressive may result in participants leaving the program. Participants will only leave the program as a result of discomfort if they realize that in fact their discomfort is a result of the program. The answers to the questions of comfort from participants that were unaware that an event took place may therefore safely be dismissed.

The levels of comfort reported by participants that stated they were aware an event had occurred are presented in Figure 33, below. The reader should keep in mind the very small sample sizes involved in this case – only 9 (out of 84) respondents asked about a curtailment event to which they were actually exposed were aware that they had been exposed to a curtailment event. Put another way, the approximately 11% of those claiming to be aware that an event occurred that were exposed to an actual (as opposed to placebo) event is in fact a single respondent.

²⁹ That is: if a surveyor asks “Were you aware of the event that occurred yesterday” the probability is quite high that in fact there was an event yesterday – otherwise why would the surveyor ask about it? A respondent wanting to appear perceptive – even if only to him or herself – will likely then say that yes, he or she was aware of the event.

The distribution of responses is not what would normally be expected. Overall, a greater proportion of those actually exposed to an event and claiming to be aware of that event than those not actually exposed to an event claimed that their comfort level was the same as normal. Likewise and unexpectedly, the only respondent claiming to be aware that an event had occurred and indicating that he or she had been very uncomfortable was in fact someone who had been exposed only to a placebo event – that respondent’s air-conditioning had not been cycled at all during the time in which he or she claims to have been very uncomfortable compared to a normal afternoon with similar outdoor temperatures.

Figure 33: Response to “How would you characterize your comfort... compared to a normal afternoon with similar outdoor temperatures?”



Source: Survey Data

What the above analysis seems to indicate is that, on the whole, participants are not bothered or made uncomfortable by curtailment events.

In the EM&V sample of survey respondents altogether three indicated that they had been “Much less comfortable” during the curtailment event. In two of these cases, however, the respondent could not remember an event having taken place (and therefore would not realistically have ascribed any discomfort to the program) and, as noted above, in the third case the discomfort was experienced on a placebo day.

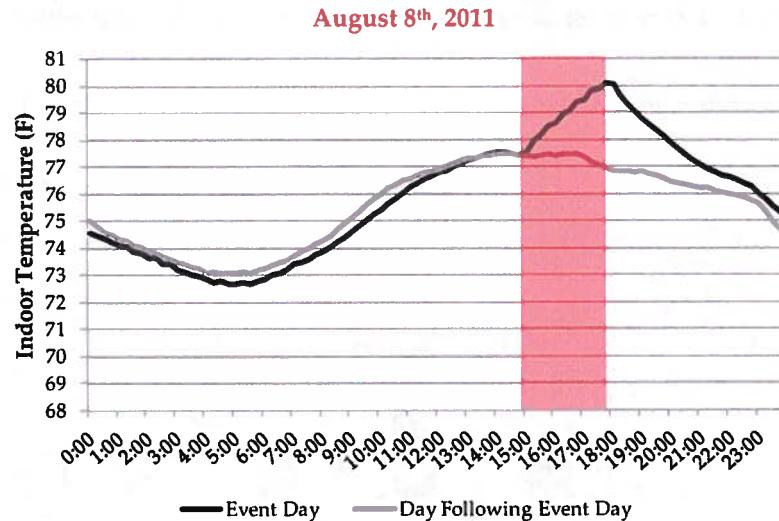
Nonetheless, it may be instructive to take advantage of the indoor temperature data logged to obtain a sense of the indoor temperatures that provoke such discomfort. Unfortunately, for the two EM&V respondents that indicated that they felt “Much less comfortable” on actual event days (as opposed to a placebo day) there is no logger data for August.

The evaluation team therefore decided that it might be a useful exercise to take a closer look at the indoor temperatures experienced by those that indicated that they were “Somewhat less comfortable”³⁰

³⁰ The highest level of discomfort on an actual event day for which any corresponding log data exists.

than normal, for the hottest day in the survey sample. In this case, that day was August 8th. Two EM&V participants surveyed about this event indicated that they were “Somewhat less comfortable” than normal for that day. In Figure 34, below, the indoor average indoor temperature (as registered by the participants’ thermostats) is shown for each hour. Note that the maximum temperature deviation is almost exactly three degrees Fahrenheit which occurs in the final interval before the end of the event.

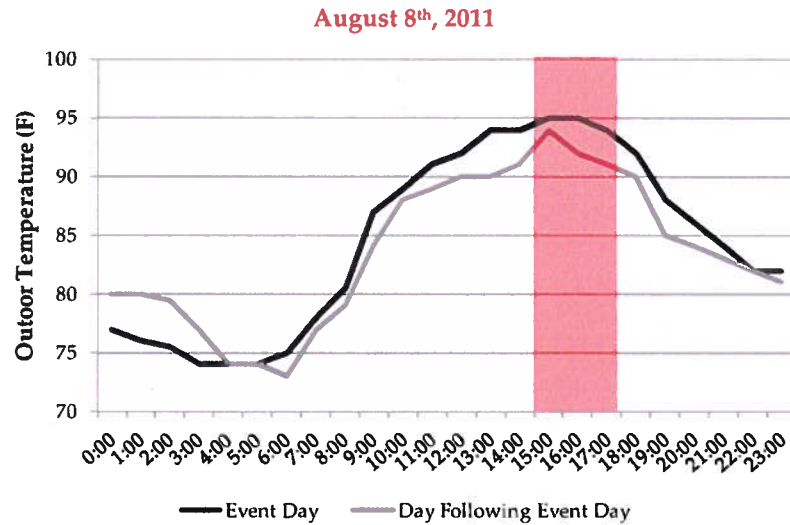
Figure 34: Average Indoor Temperature “Somewhat less comfortable” Respondents



Source: Survey Data, Navigant Logger Data and Analysis

The proximity of the two lines in the figure above in the hours leading up to the event suggest that using the day immediately following the event is, in this case a reasonably good comparator. Further examination of the outdoor temperatures to which these respondents were exposed on both days, however, suggests that not all of the deviation in indoor temperatures is due to curtailment. Although the temperature is very similar on both days in the hours leading up to the event, it is somewhat lower on the day following the event during the event hours, as may be seen in Figure 35, below.

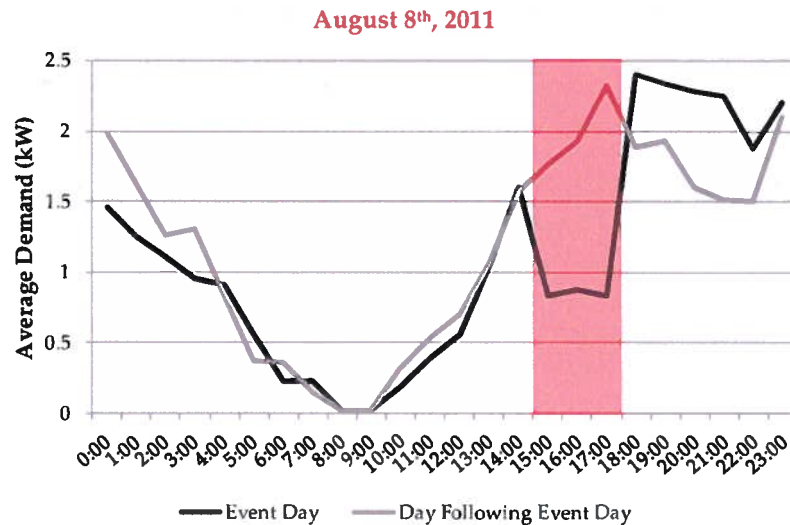
Figure 35: Average Outdoor Temperature "Somewhat less comfortable" Respondents



Source: Survey Data, Navigant Logger Data and Analysis

The difference in indoor temperature for these two respondents, while clearly somewhat influenced by the exterior temperature is just as clearly predominantly the result of A/C curtailment. This is evident when examining the average hourly load of the two respondents on the day of the event and the day following the event, as shown in Figure 36, below.

Figure 36: Average Demand (kW) "Somewhat less comfortable" Respondents



Source: Survey Data, Navigant Logger Data and Analysis

C.3 General Program Satisfaction

In addition to testing participant awareness of events and comfort during events, an important component of the four surveys was to determine the general level of satisfaction participants had with the program. PEC has already, through its own internal assessments, found that in general participants tend to have a relatively high level of satisfaction with the program.

A customer loss analysis conducted by PEC in October 2011 found that the program had an annual attrition rate of approximately 1.5 – 2%³¹, relatively low for a voluntary DR program and that of these, between 75% and 90% of participants left the program for reasons unrelated to the impacts of the control events. That is, the most important drivers of participant attrition were not customer discomfort during events (discomfort which could be mitigated by PEC's choice of cycling strategy) but rather that participants moved out of their homes or found that the control switches interfered in some way with the operation of their A/C units – drivers of attrition which PEC has very little – if any – ability to influence.

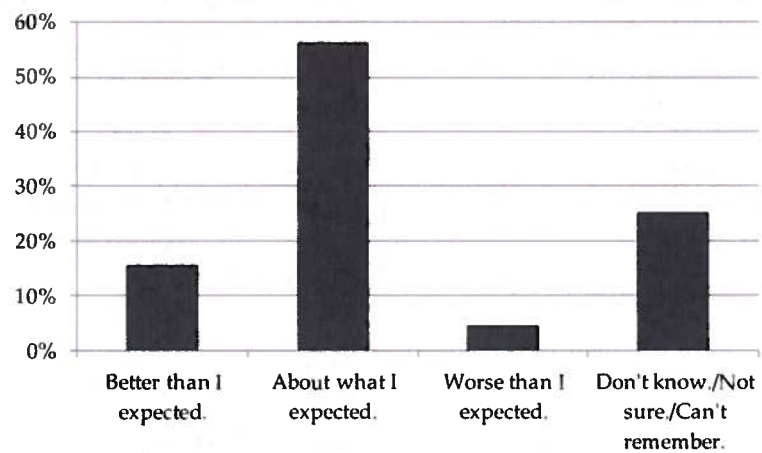
This previously observed apparent high level of satisfaction with the program amongst participants is reinforced by the results of a question posed in the four surveys used for this evaluation. The question asked on the survey was:

"Now that Progress Energy has activated your air conditioner control switch, how would you describe your experience? Would you say it was about what you expected, better than you expected, or worse than you expected?"

The distribution of answers amongst all 145 participants surveyed is shown in Figure 37, below. As may clearly be seen, very few customers have a negative view of the program and the vast majority (96%) has either no opinion at all or has a positive or neutral opinion about it. From the perspective of participant attrition this is excellent news and accords with the observations made by PEC in its analysis of customer loss. Exiting the program requires some amount of effort and hassle on the part of the participant; he or she must make phone calls, book an appointment for the removal of the control switch, ensure he or she is present for that appointment, etc. Given human nature being what it is, it seems likely that as long as the participant does not actively dislike the program – and these surveys imply only a very small percentage do actively dislike it – participants are highly unlikely to take the trouble to leave the program. Thus it seems like that, going forward, participant attrition will continue to be very small.

³¹ Progress Energy, *Summer AC Program Customer Loss Analysis*, October 2011

Figure 37: Response to "...how would you describe your experience [with the EnergyWise Program]?"



Source: Survey Data

Appendix D. Winter Device Responsiveness Analysis

This section discusses the evaluation team's analysis of the responsiveness of auxiliary heat strips to the PEC curtailment signal.

In the course of standard data diagnostics the evaluation team noted that in a large number of cases the auxiliary heat strips appeared not to have responded at all to PEC's curtailment signal, or else had only partially responded. Although some non-response must always be expected in any direct load control program, the incidence of non-response seemed abnormally high.

As a result of this initial finding, the evaluation team undertook a more extensive analysis of the responsiveness of the auxiliary heat strips³². The evaluation team's principal findings were:

- **On average, over 40% of auxiliary heat strips did not respond at all to the PEC control signal on any given event.** This non-response rate was relatively consistent, fluctuating between 35% and 45% by event.
- **On average, over 20% of auxiliary heat strips were only partially responsive to the PEC control signal when the average outdoor temperature during the event was less than 40 degrees Fahrenheit.** Given the 100% cycling strategy (i.e. complete shut off of the strips) this is puzzling; devices should either be completely responsive or completely non responsive.
- **No obvious pattern exists indicating the possible cause of auxiliary heat strip non response.** Only a very small number of devices in the EM&V sample were non responsive to all events – the majority were completely responsive for at least one winter event.

This section is divided into the following two sub-sections:

1. **Method for Determining Device Responsiveness.**
2. **Device Responsiveness Summary Statistics and Discussion.**

D.1 Method for Determining Device Responsiveness

As mentioned above, initial diagnostic examination of plots of raw logger data revealed that a very high proportion of controlled auxiliary heat strips failed to respond to PEC's curtailment signal. It was also observed that a significant proportion of auxiliary heat strips appeared to only partially respond to PEC's curtailment signal. Based on these observations, the evaluation team assigned each device/curtailment event pair to one of four categories:

- **Completely Responsive Devices:** auxiliary heat strips that completely responded to PEC's curtailment signal during a given curtailment event.

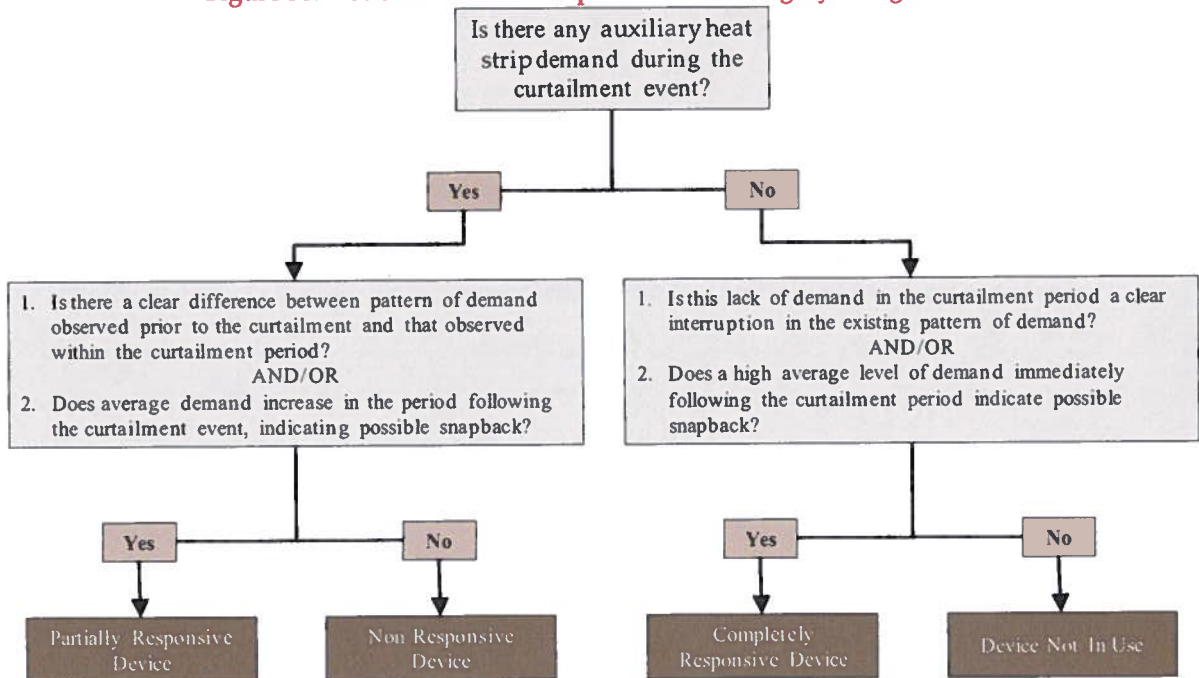
³² Similar initial diagnostics of the water heater data revealed that these devices were almost always completely responsive to the PEC curtailment signal.

- **Partially Responsive Devices:** auxiliary heat strips that appear to have responded to PEC's curtailment signal during some, but not all, of the curtailment period of a given curtailment event.
- **Non Responsive Devices:** auxiliary heat strips that do not appear to have responded at all to PEC's curtailment signal during a given curtailment event.
- **Devices Not In Use:** auxiliary heat strips that do not appear to be in use immediately before, after, or during a given curtailment event.

Assignment to each of these categories was accomplished by examining a data plot of the raw 3-minute interval logger data for each device/curtailment event pair. The category to which that device/curtailment event pair was assigned was determined by the decision tree shown in Figure 38, below. Note that this method of determining responsiveness differs from the method used to determine responsiveness for the summer analysis. This is because:

1. All events in the winter use a 100% curtailment strategy – a simple examination of a data plot is typically sufficient to determine responsiveness.
2. There were only 38 logged auxiliary heat strips curtailed for five events³³, meaning only 200 plots needed to be examined. In the summer data between 108 and 121 different devices were controlled for 11 different events – an impractically large number of device/curtailment event pairs to be examined individually.

Figure 38: Decision Tree for Responsiveness Category Assignment



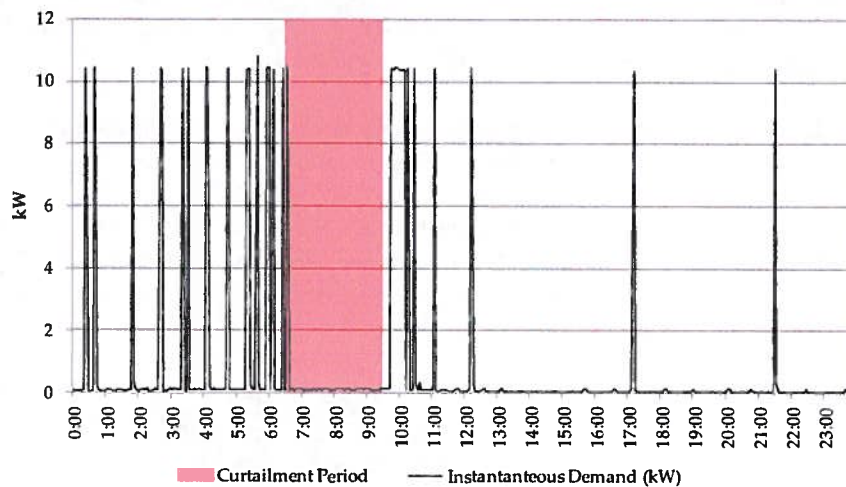
Source: Navigant Analysis

³³ For the first two events there were 39 auxiliary heat strips.

Presented below are four data plots. Each is a plot of raw 3-minute logger data for Event A on the 4th of January, 2012. The first example plot shows the demand of a device that was **completely responsive** to PEC's curtailment signal for that event. The second example plot shows a device that was **partially responsive** to PEC's curtailment signal for that event. The third example plot shows the demand of a device that was **non-responsive** to PEC's curtailment signal for that event. The fourth and final example plot shows the demand of a device that was **not in use** during the curtailment event.

For the first plot, Figure 39 below, it's clear that the auxiliary heat strip has responded completely to PEC's curtailment signal: there's a clear interruption in the existing pattern of heat strip demand, there's a period of sustained demand immediately following the curtailment period, and there is no heat strip demand at all during the curtailment period.

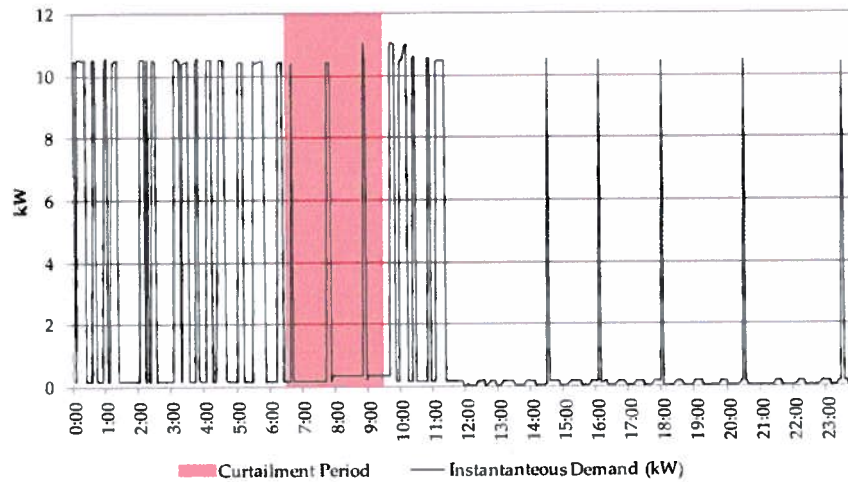
Figure 39: Three-Minute Interval Plot for Completely Responsive Device, Event A, 4 Jan 2012



Source: Navigant Logger Data and Analysis

For the second plot, Figure 40 below, the pattern of demand immediately prior to and following the curtailment period when compared with the demand within the curtailment period clearly indicates that curtailment is having some effect on demand. Unlike in Figure 39, however the heat strips are still operating at least part of the time, indicating that this device only partially responded to PEC's signal to curtail.

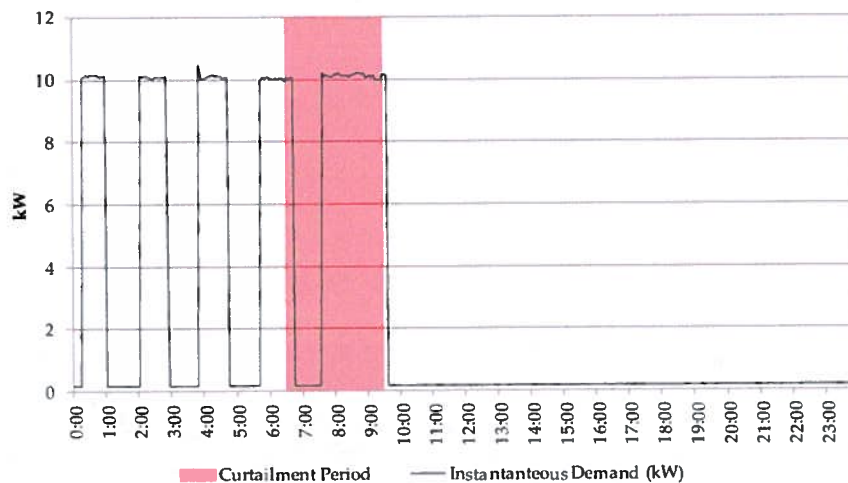
Figure 40: Three-Minute Interval Plot for Partially Responsive Device, Event A, 4 Jan 2012



Source: Navigant Logger Data and Analysis

For the third plot, Figure 41 below, the auxiliary heat strips are active for nearly the entire curtailment period and not active at all in the period immediately following the curtailment period (i.e. there is no snapback). This device is clearly not responding to PEC's curtailment signal.

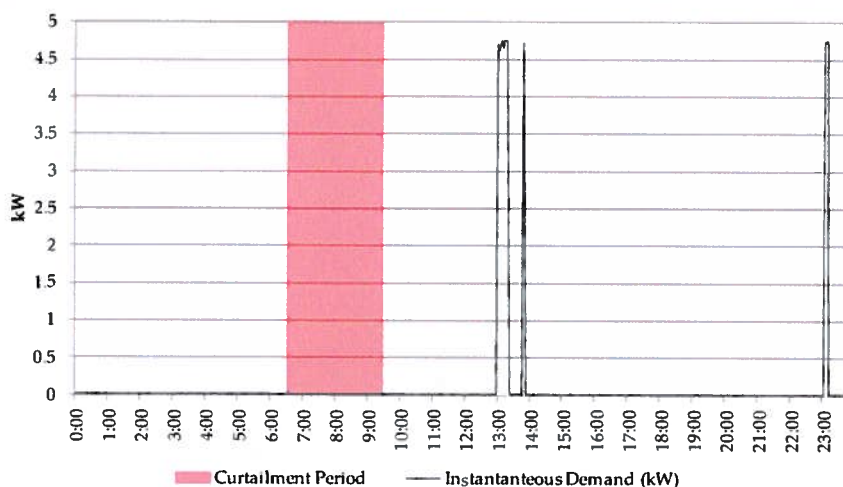
Figure 41: Three-Minute Interval Plot for Non Responsive Device, Event A, 4 Jan 2012



Source: Navigant Logger Data and Analysis

For the fourth plot, Figure 42 below, the auxiliary heat strips are not active either before or immediately following the curtailment event indicating that it is almost certain that the device was not in use during the curtailment event.

Figure 42: Three-Minute Interval Plot for Device Not In Use, Event A, 4 Jan 2012



Source: Navigant Logger Data and Analysis.

D.2 Device Responsiveness Summary Statistics and Discussion

This sub-section discusses some of the summary statistics related to the device responsiveness by category, provides some plots to demonstrate the reasonableness of the evaluation team's assignment of devices by category, and provides an indication of how frequently individual devices get assigned to each of the four categories.

After applying the decision tree shown in Figure 38 to assign one of the four categories to each of device/curtailment event pairs, the evaluation team calculated some summary statistics that confirmed the initial belief that a very high proportion of devices appeared to be not responding to PEC's curtailment signal.

The number of devices by category for each of the five curtailment events is shown in Table 16, below³⁴.

Table 16: Number of Devices by Category and Event

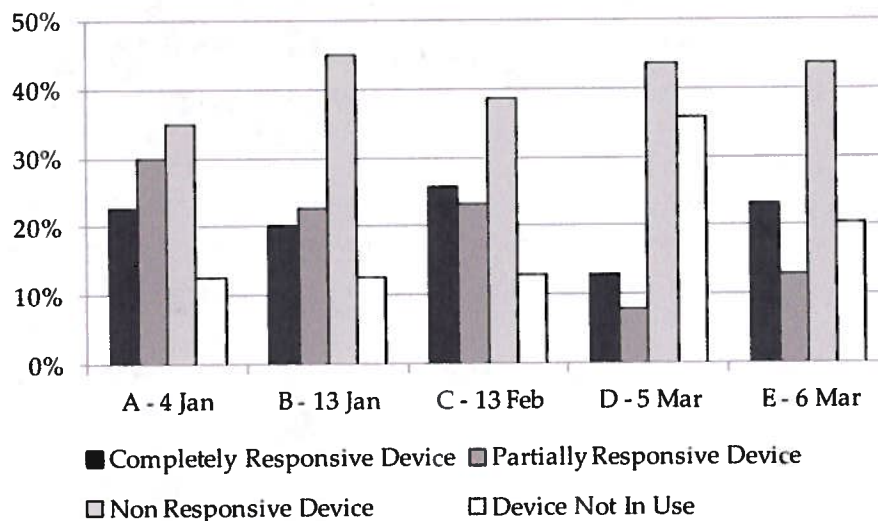
Event	Completely Responsive Device	Partially Responsive Device	Non Responsive Device	Device Not In Use	Total
A 4-Jan-12	9	12	13	5	39
B 13-Jan-12	8	8	18	5	39
C 13-Feb-12	10	9	14	5	38
D 5-Mar-12	5	2	17	14	38
E 6-Mar-12	9	5	16	8	38

Source: Navigant Logger Data and Analysis

³⁴ Note that one device's data is only available for the first two events, hence the change from 39 to 38 in the total column of Table 16.

The percentage of devices in each event falling into each of the categories is presented graphically in Figure 43, below. Note that across Events A, B, C and E the percentages are somewhat consistent, but that for Event D the number of devices not in use grows considerably, lowering the percentage of devices that either completely or partially responded to the curtailment signal. This is due to the fact that Event D (March 5th) was by far the warmest event day – the average outdoor temperature during the event was 42 degrees F compared with just 18 degrees F for Event A and between 24 and 29 degrees F on Events B, C and E.

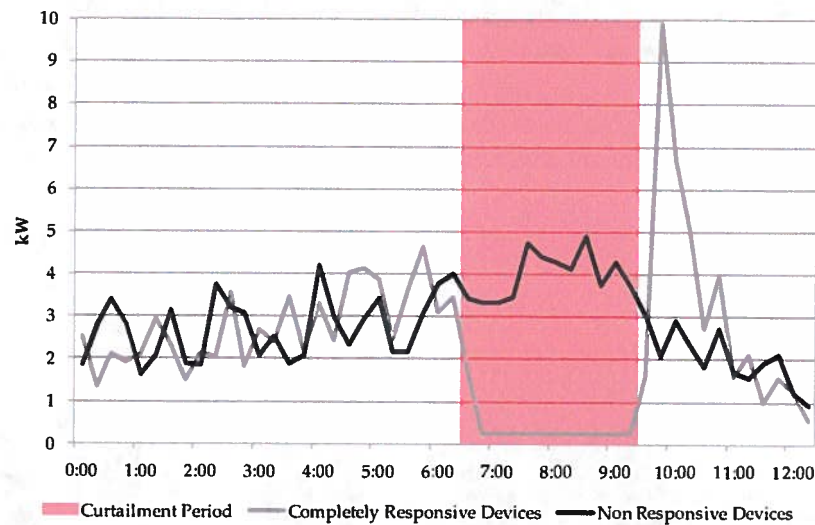
Figure 43: Percentage of Devices in Each Category, for Each Winter Event



Source: Navigant Logger Data and Analysis

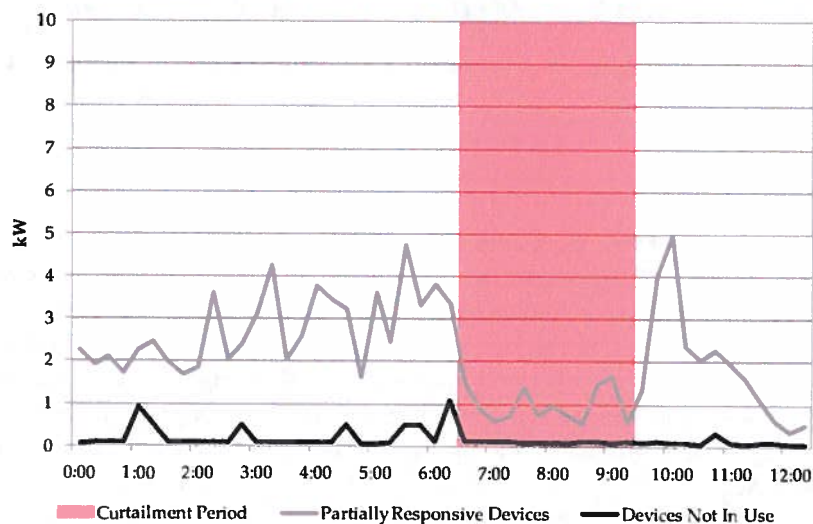
A more general sense of how devices in each of the four categories behave during events, as well as confirmation that the category assignment was reasonably accurate, may be provided by examining some plots of the average level of demand of the devices, by category. Figure 44, below, is a plot of the average demand of devices that responded completely to PEC's curtailment signal during Event A and the average demand of devices that did not respond at all to PEC's curtailment during Event A. Below that, in Figure 45, is a plot of the average demand of devices that partially responded to PEC's curtailment signal during Event A and the average demand of devices that did not appear to be in use during Event A.

Figure 44: Average Demand, Completely Responsive and Non Responsive Devices, Event A



Source: Navigant Logger Data and Analysis

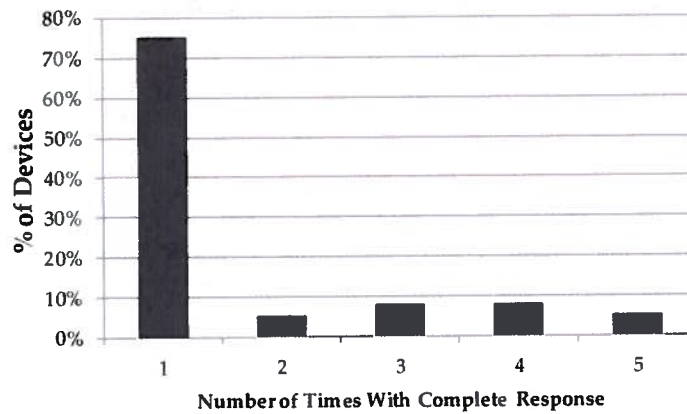
Figure 45: Average Demand, Partially Responsive and Devices Not In Use, Event A



Source: Navigant Logger Data and Analysis

Interestingly, as with the summer analysis of device responsiveness, individual devices did not systematically fall into a single category. Consider Figure 46 below which shows the percentage of devices by the number of times that they were assigned to a given category. What the tallest bar on the left hand side of this chart means is that **75% of all the EM&V devices were found to be completely responsive to the curtailment signal sent by PEC only a single time**. Conversely, only 5% - two devices - were completely responsive for all events.

Figure 46: Percentage of Devices by the Number of Times Assigned to the “Completely Responsive” Category



Source: Navigant Logger Data and Analysis

A similar distribution holds across the three other categories: approximately three quarters of devices were either partially responsive or not in use for only a single event and about 40% of devices were non-responsive only to a single event. This suggests that non-response is due not to malfunctioning devices but rather to the way the devices were connected to the heat strips or to something inherent in the design of the heat pump. The evaluation team has shared the results of its categorization with PEC to allow PEC to investigate the reasons for non- and partial-response. As yet the results of this investigation are not available.

Appendix E. Winter Indoor Temperature Impacts

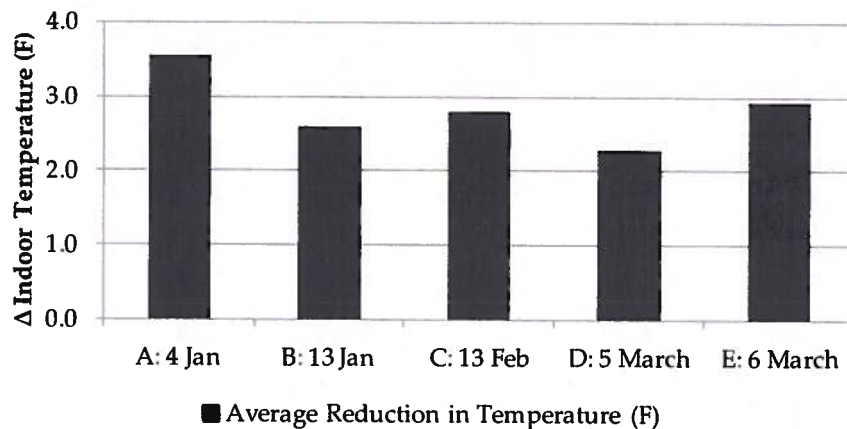
All EM&V participating auxiliary heat strips were fitted with data loggers which captured indoor temperature as well as the demand data required for the analyses above. This section contains the evaluation team's analysis of this data.

The evaluation team's principal findings with regard to indoor temperature data were that:

- **For completely responsive units, curtailment on the coldest morning event led to a fall in indoor temperatures of between just under two to nearly six degrees Fahrenheit.** This means that the lowest temperature recorded by these completely responsive units during event hours and the hour immediately following the event was, for each device, between 59 and 69 degrees Fahrenheit.
- **The average change in indoor temperature is remarkably consistent from event to event, showing only modest sensitivity to outdoor temperatures.** Despite large fluctuations in outdoor temperature (between 18 and 42 degrees Fahrenheit) the difference in indoor temperature for a given individual between event and non-event days is very similar from event to event.

As may be seen in Figure 47, below, the average difference between the coldest indoor temperature recorded by a unit during or immediately following an event, and the average temperature during the same time window on non-event days fluctuated between just over two degrees and nearly 3.5 degrees Fahrenheit by event.

Figure 47: Average Indoor Temperature Change by Event – Completely Responsive Units



Source: Navigant logger data and analysis

This section of the report provides an analysis of the manner in which completely responsive auxiliary heat strip curtailment has affected indoor temperatures.

The temperature changes discussed in this section are calculated in a slightly different way from the manner in which temperature changes were calculated for the analysis of indoor temperature in the summer. For the winter analysis, the change in indoor temperature during an event was calculated as

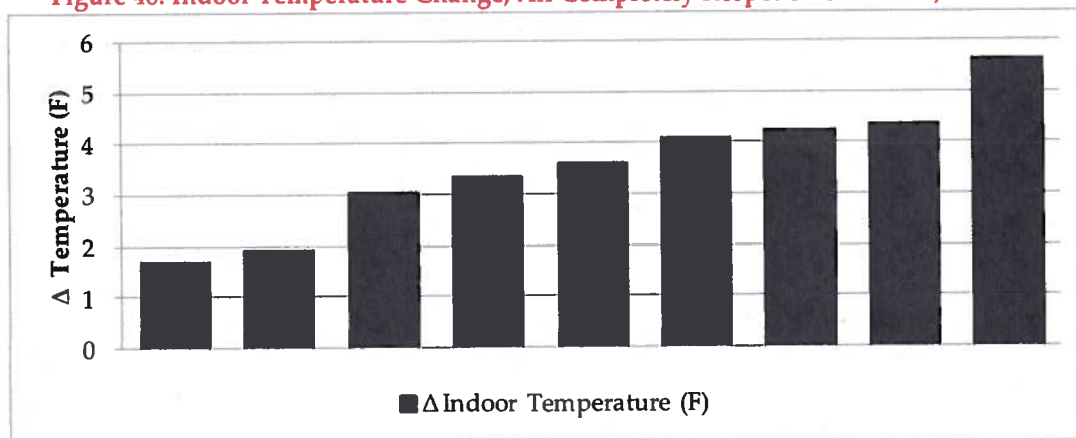
the difference between the lowest indoor temperature observed during an event or the hour immediately following it³⁵ and the average temperature observed for the same unit during the same hours on all non-event days. Recall that for the summer analysis, the temperature during the event period and the hour immediately following it was compared to the average temperature in the hour immediately preceding the curtailment event.

The evaluation team chose to change the way indoor temperature change was calculated for the winter indoor temperature analysis due to its observation that in many cases on event days, there was very little temperature change at all between the indoor temperature observed immediately prior to the event and the indoor temperature observed during the event. The evaluation team concluded that in many cases participants were making use of programmable thermostats or practicing manual set-up to ensure the house was warm when they got up in the morning. The evaluation team thus concluded it would be more appropriate to compare event indoor temperatures with average non-event indoor temperatures for the same hours, rather than the hour immediately prior to the event.

For the analysis of the effects of curtailment on indoor temperature, the evaluation team concentrated only on those devices that were assessed in Appendix D to be completely responsive. This means that the sample of device/event combinations from which to draw is relatively limited – recall that for no event did more than 10 auxiliary heat strip devices completely respond to PEC's control signal. The reader should bear this in mind when considering summary statistics such as those presented in Figure 47, above. This smaller sample size (as well as the relatively homogenous event lengths and the lack of variation in control strategy) mean that the regression analysis used for the summer temperature analysis is not practical, nor would it be likely to yield any useful information.

As noted in the principal findings, above, there is considerable variation in indoor temperature changes between devices. The difference between the average indoor temperature during event hours and the hour that followed the event on non-event days and the lowest observed indoor temperature during event hours and the hour immediately following event hours for each completely responsive device for Event A (4th Jan) is presented in Figure 48 below.

Figure 48: Indoor Temperature Change, All Completely Responsive Devices, Event A

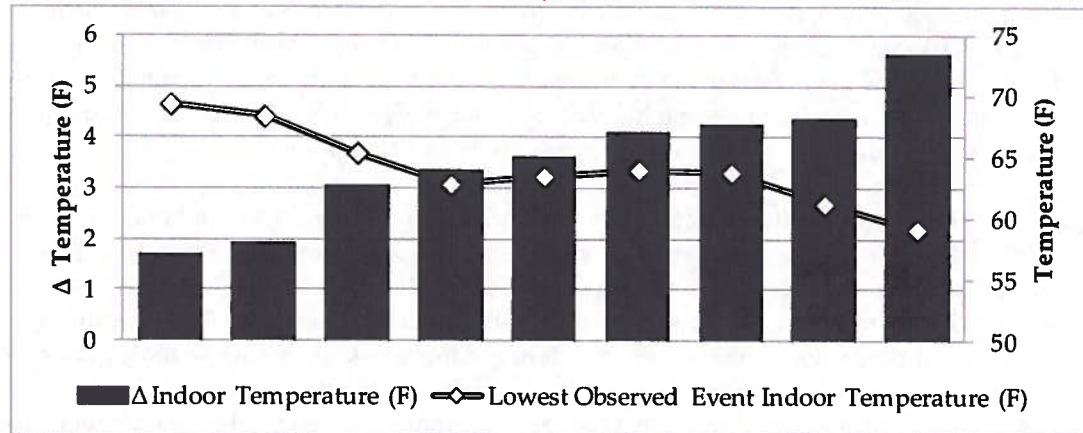


Source: Navigant logger data and analysis

³⁵ To allow for the possibility that, like in the summer, indoor temperature lags curtailment somewhat.

Note that four out of the nine devices – nearly half – that were completely responsive to Event A recorded indoor temperatures that were more than four degrees colder than they otherwise usually were. The reader may be able to get a sense of how uncomfortable participants in the households with these devices may have been during events should we superimpose on Figure 48, the minimum indoor temperature observed during the curtailment event or the hour immediately following it. This is shown in Figure 49, below. The diamond markers (right axis) connected by the white line indicate the lowest indoor temperature observed during the event, or the hour immediately following the event.

Figure 49: Indoor Temperature Change and Indoor Temperature Level, All Completely Responsive Devices, Event A

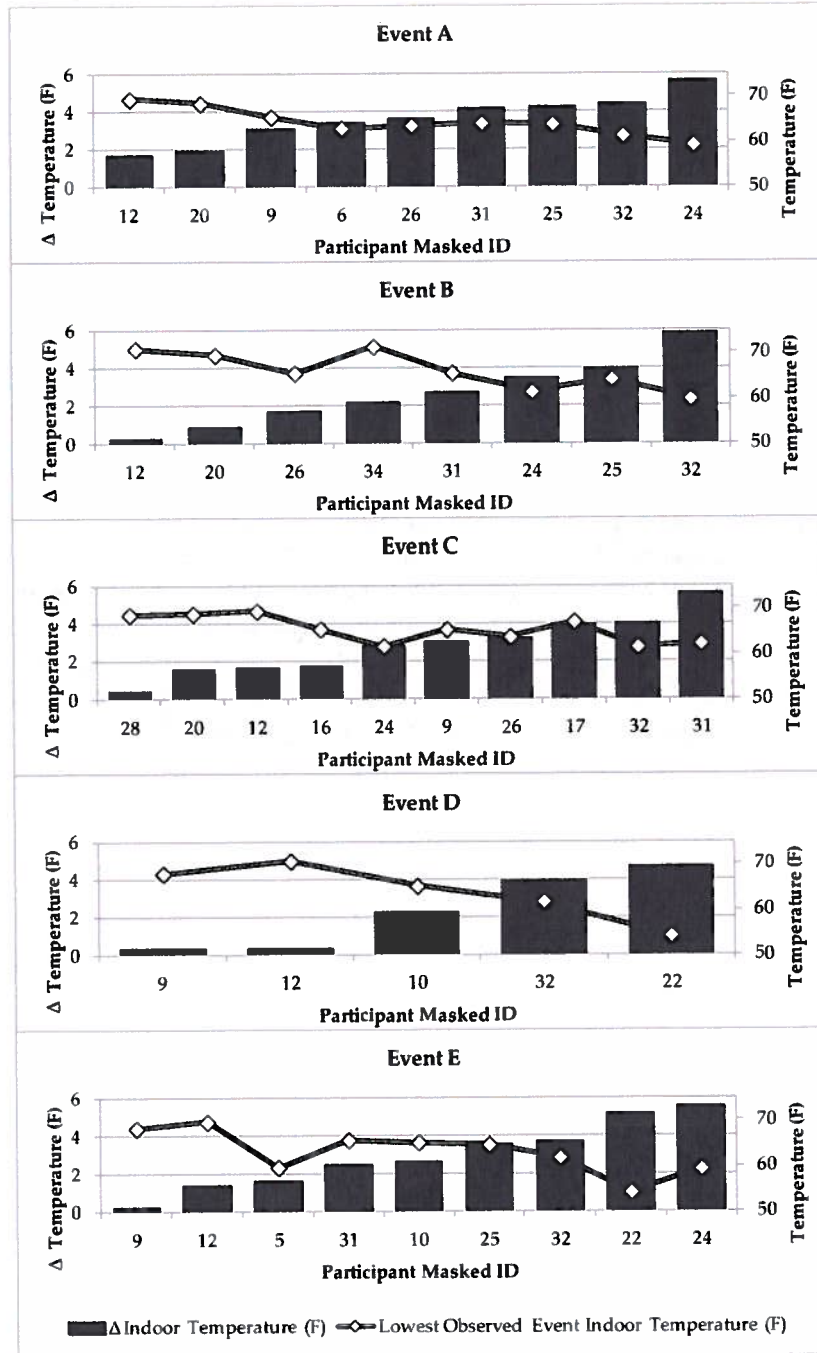


Source: Navigant logger data and analysis

In Figure 49 it may be seen that the device that recorded the largest deviation from normal temperatures (the one on the far right) the lowest recorded indoor temperature at the time of the event was less than 60 degrees Fahrenheit. Note that by adding the change in temperature (black bar) to the lowest observed event temperature (white diamond) we can obtain the indoor temperature typically observed for this device during the same hours as the event, on non-event days: in this case about 65 degrees Fahrenheit. Although the participant associated with this device was not one of those surveyed, the evaluation team believes it is likely that this participant would have been in some discomfort on the morning of January 4th due to experiencing temperatures of less than 60 degrees F in his or her home (over five degrees less than normal for that time).

In Figure 50, below, the evaluation team has produced the figures equivalent to Figure 49 for all five events to provide the reader with a sense of how the distribution of temperature changes shifts for each event. In a number of cases, a given device completely responded to the PEC signal for more than one event. The evaluation team has labeled each of the column charts below such that the reader may compare an individual device's indoor temperature change in one event to another event (i.e., it is possible to see if certain individuals always have very large changes in indoor temperature). The individual device labeling used is a "Masked ID", an arbitrary assignment of a number between 1 and 39 to each participating EM&V device. The indoor temperature impacts for all completely responsive devices over all events are shown in Figure 50, below.

Figure 50: Indoor Temperature Change and Indoor Temperature Level, All Completely Responsive Devices, All Events



Source: Navigant logger data and analysis

Several points of interest stand out in Figure 50. Note that when a given individual device is completely responsive for more than one event, the change in indoor temperatures for both events is remarkably consistent from event to event. Consider for instance Masked ID 32, an individual device that successfully responded to PEC's control signal for every single event (one of two devices that was

completely responsive for all events). For each event, an indoor temperature change of about four degrees has been estimated, despite the fact that the outdoor temperature varied considerably across events, from between 18 and 42 degrees Fahrenheit.

Given the consistency of the indoor temperature impacts the two most likely drivers of the change in indoor temperature compared to a non-event day are:

1. The “leakiness” of the house, and;
2. The magnitude of the overnight temperature setback used by participants.

Understanding these drivers, what can PEC do to reduce the discomfort felt by participants on event days?

Addressing the building envelope is clearly beyond the mandate of the EnergyWise program, and trying to target only customers with tight building envelopes for participation in the program would be impractical.

One way in which PEC could help reduce participant discomfort during events would be to provide participants with a warning the night before an event. This would then allow participants to pre-heat the home and remain comfortable during the event. The decision to provide warning should, however be considered carefully – as noted in Section Appendix C participants are more likely to believe they have been made uncomfortable by an event if they are informed about event timing than if they are not. PEC may wish to consider a survey experiment next winter and compare demand and temperature impacts for a group of participants that are warned about an event ahead of time, and a another group that are not warned.

Appendix F. Winter Participant Perceptions Analysis

This section presents the findings of the evaluation team's analysis of two surveys of winter season EnergyWise participants conducted in February and March of 2012. The principal purpose of the survey was to determine the degree to which participants were aware of curtailment events, and if aware, what changes participants noticed during the event. In addition, the survey was conducted to evaluate customer satisfaction with the program.

The evaluation team's principal findings of the analysis of participant perception were:

- **Most participants are unaware of curtailment events when they occur.** 95% of survey respondents indicated that they were not aware that a curtailment event had occurred in the previous few days.
- **Very few participants that were exposed to an actual curtailment event noticed changes in indoor air temperature and comfort level, or water temperature.** In fact, the same number of placebo respondents noticed a "change" as non-placebo respondents.
- **Participants are generally satisfied with the EnergyWise program.** Over a quarter of all respondents indicated that their experience with the program was "better than expected" and only 1% indicated that their experience with the program was "worse than I expected" with the balance of respondents unsure or indicating that their experience with the program was "about what I expected".

This section is divided into the following sub-sections:

1. **Survey Response:** this sub-section briefly describes survey respondents.
2. **Awareness of Event:** how aware were respondents that an event had occurred?
3. **Changes Noticed During Event:** what changes did the participant notice during the event?
4. **General Program Satisfaction:** how happy are participants with the program?

F.1 Survey Response

Respondents to each survey can be divided into two groups: EM&V participants and non-EM&V participants. EM&V participants are those participants for whom the evaluation team has logger data (used to estimate impacts). Non-EM&V participants are those participants in the program for whom the evaluation team has no logger data. All participants, both EM&V and non-EM&V, were surveyed within a few days of the curtailment events. However, the curtailment events on March 5th and 6th were only applied to EM&V participants. As a result, non-EM&V participants surveyed in March convey customer perceptions in response to a "placebo" event. Evaluating customer perceptions in response to a placebo event allows the evaluation team to qualitatively assess bias in the survey responses of participants. The number of survey respondents for each event is shown below in Table 17. Cells highlighted in red indicate a placebo event for the given sub-sample.

Table 17: Survey Participation and Placebo Events

	EM&V Sample	Non EM&V Sample
13-Feb-12	20	108
5-Mar-12	18	103
6-Mar-12	15	118
Number Surveyed About ACTUAL Event	53	108
Number Surveyed About PLACEBO Event	n/a	221
Total Surveyed:	53	329

 = Placebo Event (no curtailment)

Source: Survey Data and PEC EW Control Event Tracking Report

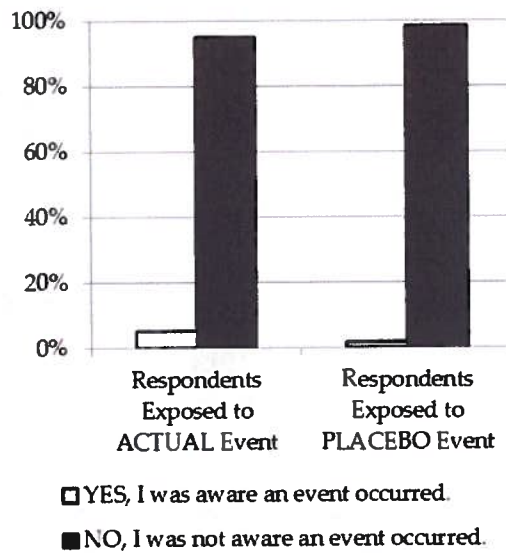
F.2 Awareness of Event

The most basic question the survey was designed to answer, and one which was put directly to survey respondents, is simply:

"Were you aware that a cycling event occurred?"

The distribution of survey responses, differentiating between respondents that experienced an actual curtailment event and those that experienced a placebo event, is shown in Figure 51. The primary finding is that the vast majority of participants (95%) that were exposed to an actual curtailment event were unaware that the event had occurred. Interestingly, participants that were aware of actual events were only aware of the event that took place on February 13th, and not the events on March 5th or 6th. This may be due to slightly lower average outdoor air temperatures during the curtailment event in February (25 degrees Fahrenheit) compared to either curtailment event in March (42 degrees on March 5th and 27 degrees on March 6th).

Figure 51: Responses to “Were you aware that a cycling event occurred?”



Source: Survey Data

A higher proportion of respondents exposed to an actual event claimed to be aware of an event compared with participants exposed to a placebo event. However, the fact that some respondents exposed to a placebo event claimed to be aware of an event reveals some survey bias. Survey bias often arises as respondents perceive the survey as if it was a test and respond in a way that they believe is the “correct” response.³⁶

Participants in the EnergyWise program may have load control switches on their auxiliary strip heat on central electric heat pump, electric water heaters, or both. To further understand customer awareness of cycling events the evaluation team repeated the qualitative analysis above distinguishing between participants with a heat strip switch and a water heater switch. It is likely that participants will be more receptive to a heat strip cycling event than a water heater cycling event. The distribution of survey responses are shown in Figure 52 and Figure 53. These charts suggest that this is in fact the case. In particular, 7% of participants exposed to an actual heat strip event were aware that the event occurred, while only 5% of participants exposed to a water heater cycling event reported being aware of the event. It is also interesting to note that a larger proportion of respondents reported being aware of a water heating cycling placebo event (2%) compared to a heat strip cycling placebo event (1%). Nevertheless, regardless of the type of curtailment event, awareness remains low.

³⁶ For example, if a surveyor asks “Were you aware of the cycling event that occurred yesterday?” the probability is quite high that there was in fact an event yesterday – otherwise, why would the surveyor ask about it? A respondent wanting to appear perceptive will likely say that he or she was aware of the event.

Figure 52: Responses to “Were you aware that a cycling event occurred?”

Participants with a Heat Strip Load Control Switch

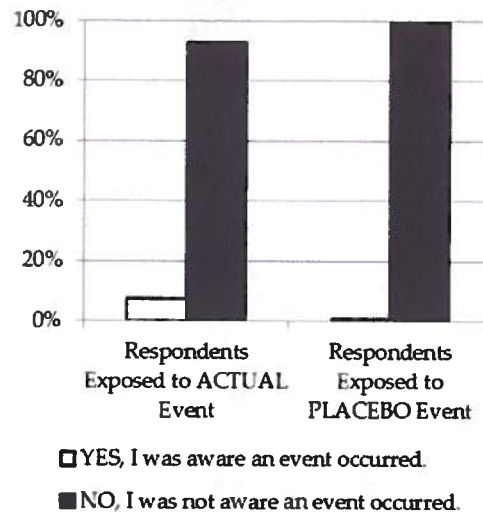
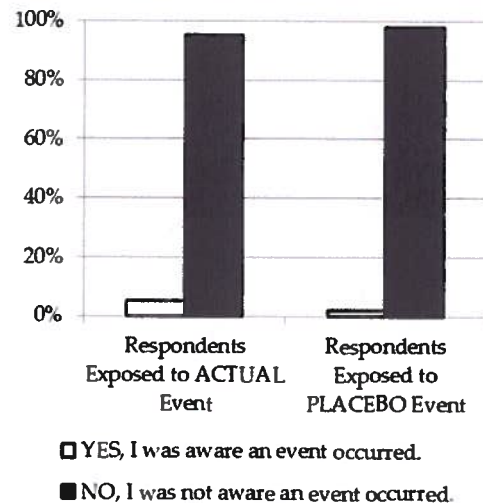


Figure 53: Participants with a Water Heater Load Control Switch



Source: Survey Data

An important caveat worth noting is that the load control switches do not always perform as expected. As a result, participants who would have otherwise been exposed to an event may not experience the event due to a device not responding to the PEC control signal. The analysis above does not differentiate between customers exposed to an event where the switch was completely, partially or non-responsive or where auxiliary heat strips were not in use during the event. It is important to take this into consideration so as not to over- or under-state awareness of events. For example, if the load control switches of customers that did not notice an “actual” event were completely responsive, we can be confident in stating that a awareness of events is low.

As noted in Appendix D, water heater switches operated as expected most of the time, however, the auxiliary heat strip switches were found to be non responsive 41% of the time (averaged over the February and two March events). Because of the high rate of non responsive auxiliary heat strip switches the evaluation team re-examined awareness of actual heat strip events accounting for whether the switch functioned properly. As a reminder, 93% of customers exposed to an actual event indicated they were not aware of the event, while 7% indicated they were aware of the event. Of the EM&V customers who indicated they were not aware of the event, 52% of the heat strip switches were either completely or partially responsive while 30% were not.³⁷ This finding suggests that the percent of customers that are unaware of an event may be slightly overstated. There was only one EM&V customer who indicated he/she was aware of the event; their switch functioned properly.

F.3 Changes Noticed During Event

Awareness of a curtailment event is an important indicator, but it may also be useful to explore what changes customers noticed who were aware that an actual curtailment event occurred. For example, did customers that experienced an auxiliary heat strip curtailment event experience a change in comfort? Or, what did customers notice about their water when a water heater curtailment event occurred? A principal concern with DR programs is that if the program is too aggressive, customers will discontinue participation. While only a small proportion of participants were aware of actual curtailment events, the evaluation team reviewed these participants' survey responses in more detail to gain insight into any changes noticed during curtailment events.

Only two participants out of four who claimed to be aware of an auxiliary heat strip curtailment event indicated that they noticed a change in the temperature of their home.³⁸ One of these respondents did not actually experience a curtailment event (i.e. the survey inquired about a placebo event). The participant that did experience an actual event and was aware of the event reported that the temperature of their home fell by 5-6 degrees Fahrenheit.³⁹ This participant reported being "much more uncomfortable" and used a space heater to make their home more comfortable. It is important to remember, however, that only 1 participant out of 96 (or approximately 1%) that experienced a heat strip cycling event was aware of the event and experienced discomfort.

Only two participants out of six who claimed to be aware of a water heater curtailment event indicated that they noticed a change in how their water heater worked.⁴⁰ One of these respondents did not actually experience a curtailment event. The participant that did experience the event reported that "the water did not get as hot as usual." Again, it is important to remember that only 1 participant out of 142 (or approximately 0.7%) that experienced a water heater cycling event noticed a change in their water temperature.

³⁷ The remaining amount reflects heat pumps that were not in use before or during the event.

³⁸ A total of 8 participants reported being aware of a heat strip curtailment event; however, only 4 participants responded to survey questions on changes noticed during the event.

³⁹ Note that we cannot verify that this participant's heat strip switch functioned properly because they are in the non-M&V sample.

⁴⁰ A total of 11 participants reported being aware of a water heater curtailment event; however, only 6 participants responded to survey questions on changes noticed during the event.

F.4 General Program Satisfaction

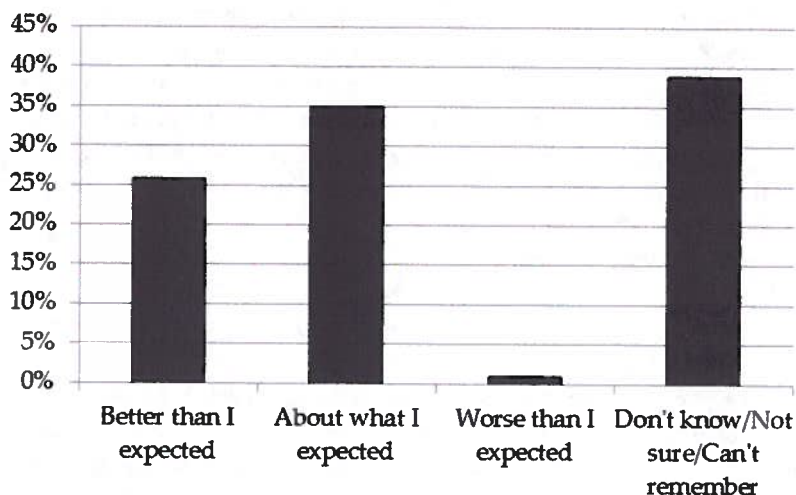
In addition to participant awareness of events, an important component of the two surveys was to determine the general level of satisfaction participants had with the program. As noted in Section Appendix C, internal PEC analysis indicates a relatively low rate of program attrition, indicating general satisfaction with the program among participants.

The high level of customer satisfaction with the program is reinforced through survey responses. In Figure 54, the distribution of responses to the following survey question is shown:

"After this cycling event, how would you describe your experience? Would you say it was about what you expected, better than you expected, or worse than you expected?"

The distribution of survey responses reveals that very few customers have a negative view of the program and the majority (99%) has either no opinion, a neutral opinion, or a positive opinion. This finding is consistent with the low attrition rates found by PEC's analysis. Given the low occurrence of customer dissatisfaction and that exiting the program requires time and effort on the part of the participant - and humans by nature have a tendency to maintain the status quo - it is likely that participant attrition will remain small.

Figure 54: Response to "...how would you describe your experience [with the EnergyWise Program]?"



Source: Survey Data

Appendix G. Summer Estimation Details and Model Specification.

This appendix will provide more detail on the methods employed by the evaluation team to estimate the historic summer 2011 demand impacts and forecast the DR capability of the various types of cycling strategies.

G.1 Summer Model Specification and Details

Two different model specifications were used to estimate summer demand reduction impacts: one for the 50% events and another for the 65%, 75% and 100% events. This approach was taken due to the fact that while there were multiple events called using a 50% cycling strategy, only a single one was called for each of the other three strategies. The reason that two models were required will become apparent and be further expanded upon below.

The data set used to estimate the models below included all quarter hours for all households with useable data from quarter hour starting 41 (10:00 am) to quarter hour starting 88 (9:45 pm). That is all observations are drawn from between 10:00 am and 10:00 pm. A separate regression equation was estimated for each strategy. The data set for each cycling strategy's regression included only non-event days and event days on which that cycling strategy was employed. For example, when the impact of the 65% cycling strategy was to be estimated, only non-event days and the day on which the 65% cycling strategy was used were included in the data set.

50% Events

The model used to estimate both historic summer 2011 50% cycling strategy impacts and forecast the DR capability at a variety of temperatures of the 50% cycling strategy is:

$$y_{k,t} = \alpha_k + \sum_{i=41}^{87} (\beta_i^{qh} \cdot qh_{i,t}) + \sum_{i=41}^{87} (\beta_i^{CDH} \cdot qh_{i,t} \cdot CDH_{k,t}) + \sum_{i=41}^{87} (\beta_i^{THI} \cdot qh_{i,t} \cdot MA_THI_{k,t}) + \sum_{i=41}^{87} \beta_i^c \cdot qh_{i,t} \cdot c_t \cdot CDH_{k,t} + \sum_{r=1}^{22} \beta_r^s \cdot s_{r,t} + \varepsilon_t$$

Where:

- $y_{k,t}$ = The average A/C demand of household k in quarter hour t .
- $qh_{i,t}$ = A dummy variable equal to one if i is equal to the quarter hour in which t happens to be. For example if quarter hour t fell in the first quarter hour of the day then $qh_{1,t}$ would equal one and $qh_{2,t}$ to $qh_{87,t}$ would all be equal to zero.
- $CDH_{k,t}$ = The cooling degree hours observed in quarter hour t . For this study CDH is defined as the greater of either the temperature in Fahrenheit less 70 degrees or zero, whichever is greater.
- $MA_THI_{k,t}$ = Is a moving average of the temperature-humidity index over the 48 quarter-hourly periods immediately preceding t . The temperature humidity index used

for this moving average is the same as that used by last year's EnergyWise evaluator and that used by PJM⁴¹:

$$THI = DB - 0.55 \cdot (1 - RH) \cdot (DB - 55)$$

Where:

DB = Dry bulb temperature (in Fahrenheit)

RH = Relative humidity (as a percentage)

c_t = Is a dummy variable equal to one if there is a curtailment event of the relevant cycling strategy taking place in quarter hour t and zero otherwise.

$s_{r,t}$ = A group of dummy variables intended to capture the effect of snapback in the quarter hours following the end of the curtailment period. The r -th dummy is equal to one if quarter hour t is the r -th hour following the end of a curtailment event. For example if the last quarter hour of a curtailment event occurred in period $t=500$, in period $t=501$, $s_{r=1,t=501}$ would be equal to one, whereas $s_{r=2,t=501}$ and all the snapback dummies for periods $r \neq 1$ would be equal to zero.

The parameter estimates obtained from this model (and found later in this appendix) were used to calculate the estimated impact of each of the curtailment events and the forecast capability at a variety of temperatures.

The reader will note that there is no intercept dummy to flag a curtailment period in this model, only a slope (or interactive) curtailment dummy. That is, the level of impact yielded by the 50% cycling strategy is purely a function of the cooling degree hours (temperature) – if cooling degree hours are equal to zero, so too is the estimated impact of A/C curtailment. This is this way by construction – the CDH threshold (70 degrees) was chosen specifically such that when the above model included an intercept curtailment dummy its estimate was very close to zero and/or non-significant.

65%, 75% and 100% Events

The model used to estimate both historic summer 2011 50% cycling strategy impacts and forecast the DR capability at a variety of temperatures of the 50% cycling strategy is:

$$y_{k,t} = \alpha_k + \sum_{i=41}^{87} (\beta_i^{qh} \cdot qh_{i,t}) + \sum_{i=41}^{87} (\beta_i^{CDH} \cdot qh_{i,t} \cdot CDH_{k,t}) + \sum_{i=41}^{87} (\beta_i^{THI} \cdot qh_{i,t} \cdot MA_THI_{k,t}) + \sum_{i=41}^{87} \beta_i^c \cdot qh_{i,t} \cdot c_t + \sum_{r=1}^{22} \beta_i^s \cdot s_{r,t} + \varepsilon_t$$

Where all variables and parameters carry the same definitions as above

Note that the only difference between the model specification above and that for 50% events is that the model specification for the 65%, 75% and 100% events contains only an intercept dummy variable to

⁴¹ PJM, *PJM Manual 19: Load Forecasting and Analysis*, Effective Date: Feb 2012

<http://pjm.com/~media/documents/manuals/m19.ashx>

account for curtailment events, rather than an interactive, or slope, dummy. This decision was made due to the fact that for each of these three cycling strategies there was only a single event. Since there is a very small range of temperatures observed for each of the various cycling events, while a parameter

estimate based on an interactive dummy (i.e., $\sum_{i=41}^{87} \beta_i^c \cdot qh_{i,t} \cdot c_i \cdot CDH_{k,t}$) would provide a reasonable

estimate of impacts for the actual event, basing a forecast of capability on this parameter could be problematic since the parameter has been estimated based on only a single observation of temperature. A forecast of capability for the 65%, 75% and 100% events may be inaccurate if calculated based on the parameter estimate attached to an interactive dummy such as the one used for the 50% events.

To obtain a slope from which capability for the 65%, 75% and 100% cycling strategies could be forecast, the evaluation team simply divided the estimated parameter values β^c by the number of coincident CDH. This delivers a linear relationship between temperature and demand reduction impacts that is anchored on two points: the estimated impact of the actual event, and the estimated impact at 0 CDH – 0 kW.

G.2 Slope and CDH Values Coincident with Events

Readers may use the numbers presented in this sub-section either to generate quarter-hourly specific estimates of historical impacts or quarter-hourly specific forecasts of capability for the various different cycling strategies. No slope estimates exist in quarter hours in which a given cycling strategy was not employed. To obtain forecast capability, the reader needs only multiply the estimated slope in Table 18 by the values in Table 19 or Table 20 and by the values in Table 21 or Table 22. Note that the slope for the 50% cycling strategy is the actual parameter estimate for the model specification for 50% events, above, whereas the slope for the 65%, 75% and 100% cycling strategies is derived as described in the section above

Impacts reported in the body of this report were based on event averages, for an example of the calculation, see G.3, below. Note that because the regression parameter estimates are capturing a reduction in demand, the slopes presented below appear as negative numbers.

Table 18: Slope Estimates by Cycling Strategy

Quarter Hour Number	Interval Time Starting	50% Cycling	65% Cycling	75% Cycling	100% Cycling
60	14:45	0.0000	0.0000	0.0000	0.0000
61	15:00	-0.0155	0.0000	-0.0219	0.0000
62	15:15	-0.0351	0.0000	-0.0495	0.0000
63	15:30	-0.0311	0.0000	-0.0564	-0.0604
64	15:45	-0.0368	0.0000	-0.0589	-0.0648
65	16:00	-0.0309	0.0000	-0.0564	-0.0678
66	16:15	-0.0344	-0.0139	-0.0551	-0.0673
67	16:30	-0.0345	-0.0462	-0.0534	0.0000
68	16:45	-0.0349	-0.0438	-0.0590	0.0000
69	17:00	-0.0332	-0.0430	0.0000	0.0000
70	17:15	-0.0332	-0.0425	0.0000	0.0000
71	17:30	-0.0295	-0.0445	0.0000	0.0000
72	17:45	-0.0315	-0.0416	0.0000	0.0000
73	18:00	0.0000	-0.0426	0.0000	0.0000
74	18:15	0.0000	0.0000	0.0000	0.0000

Table 19: Curtailment Event Dummy Variable (Part 1)

Quarter Hour Number	Interval Time Starting	Event A 1-Jun-11	Event B 9-Jun-11	Event C 22-Jun-11	Event D 12-Jul-11	Event E 13-Jul-11
60	14:45	0	0	0	0	0
61	15:00	0	0	0	1	0
62	15:15	0	0	0	1	0
63	15:30	0	1	0	1	0
64	15:45	0	1	0	1	0
65	16:00	1	1	0	1	1
66	16:15	1	1	1	1	1
67	16:30	1	1	1	1	1
68	16:45	1	1	1	1	1
69	17:00	1	1	1	1	0
70	17:15	1	1	1	1	0
71	17:30	1	0	1	1	0
72	17:45	1	0	1	1	0
73	18:00	0	0	1	0	0
74	18:15	0	0	0	0	0

Table 20: Curtailment Event Dummy Variable (Part 2)

Quarter Hour Number	Interval Time Starting	Event F 22-Jul-11	Event G 29-Jul-11	Event H 4-Aug-11	Event I 8-Aug-11	Event J 22-Aug-11	Event K 25-Aug-11
60	14:45	0	0	0	0	0	0
61	15:00	1	1	1	1	1	0
62	15:15	1	1	1	1	1	0
63	15:30	1	1	1	1	1	1
64	15:45	1	1	1	1	1	1
65	16:00	1	1	1	1	1	1
66	16:15	1	1	1	1	1	1
67	16:30	1	1	1	1	1	0
68	16:45	1	1	1	1	1	0
69	17:00	1	1	1	1	0	0
70	17:15	1	1	1	1	0	0
71	17:30	0	0	1	1	0	0
72	17:45	0	0	1	1	0	0
73	18:00	0	0	0	0	0	0
74	18:15	0	0	0	0	0	0

Table 21: Curtailment Event Cooling Degree Hours (Part 1)⁴²

Quarter Hour Number	Interval Time Starting	Event A 1-Jun-11	Event B 9-Jun-11	Event C 22-Jun-11	Event D 12-Jul-11	Event E 13-Jul-11
60	14:45	21.5	21.7	22.2	25.1	25.2
61	15:00	21.9	21.9	22.4	25.5	24.6
62	15:15	22.2	21.9	22.5	25.7	24.1
63	15:30	22.3	21.9	22.5	25.9	23.6
64	15:45	22.2	21.8	22.4	25.9	22.8
65	16:00	22.1	21.7	22.3	26.0	22.1
66	16:15	22.0	21.4	22.1	26.0	21.5
67	16:30	21.9	21.1	22.0	26.0	20.9
68	16:45	21.6	20.5	21.8	26.0	19.8
69	17:00	21.3	19.8	21.6	25.9	18.0
70	17:15	21.0	19.1	21.4	25.9	16.6
71	17:30	20.7	18.7	21.0	25.7	15.7
72	17:45	20.4	18.0	20.4	25.3	15.1
73	18:00	20.0	17.2	19.5	24.9	14.3
74	18:15	19.7	16.6	18.8	24.4	13.8

⁴² To obtain temperature in Fahrenheit, add 70 to these values.

Table 22: Curtailment Event Cooling Degree Hours (Part 2)⁴³

Quarter Hour Number	Interval Time Starting	Event F 22-Jul-11	Event G 29-Jul-11	Event H 4-Aug-11	Event I 8-Aug-11	Event J 22-Aug-11	Event K 25-Aug-11
60	14:45	27.4	28.5	24.0	24.8	17.3	19.3
61	15:00	27.2	28.7	23.9	25.0	17.3	19.5
62	15:15	27.1	28.9	23.9	25.1	17.3	19.6
63	15:30	27.1	29.0	23.8	25.1	17.2	19.7
64	15:45	27.1	29.2	23.8	24.9	16.9	19.7
65	16:00	27.2	29.2	23.8	24.6	16.7	19.8
66	16:15	27.2	29.3	23.8	24.4	16.5	19.8
67	16:30	27.2	29.2	23.7	24.2	16.5	19.7
68	16:45	27.0	29.0	23.6	23.9	16.5	19.6
69	17:00	26.8	28.7	23.5	23.6	16.6	19.5
70	17:15	26.5	28.4	23.3	23.3	16.7	19.3
71	17:30	26.2	28.1	23.2	23.0	16.6	19.1
72	17:45	25.7	27.8	22.8	22.5	16.4	18.8
73	18:00	25.0	27.4	22.4	22.0	15.9	18.4
74	18:15	24.4	27.1	22.0	21.5	15.5	18.0

⁴³ To obtain temperature in Fahrenheit, add 70.

G.3 Example Calculation

The reader may find an example calculation helpful. The calculation of the DR impact for Event A is presented in Table 23, below.

Table 23: Example Calculation for Event A (June 1, 2011) Impact

Quarter Hour Number	Interval Time Starting	Slope Estimate		Curtailment Dummy		CDH		Demand Impact
60	14:45	0.0000	×	0	×	21.5	× (-1) =	0.0
61	15:00	-0.0155	×	0	×	21.9	× (-1) =	0.0
62	15:15	-0.0351	×	0	×	22.2	× (-1) =	0.0
63	15:30	-0.0311	×	0	×	22.3	× (-1) =	0.0
64	15:45	-0.0368	×	0	×	22.2	× (-1) =	0.0
65	16:00	-0.0309	×	1	×	22.1	× (-1) =	0.7
66	16:15	-0.0344	×	1	×	22.0	× (-1) =	0.8
67	16:30	-0.0345	×	1	×	21.9	× (-1) =	0.8
68	16:45	-0.0349	×	1	×	21.6	× (-1) =	0.8
69	17:00	-0.0332	×	1	×	21.3	× (-1) =	0.7
70	17:15	-0.0332	×	1	×	21.0	× (-1) =	0.7
71	17:30	-0.0295	×	1	×	20.7	× (-1) =	0.6
72	17:45	-0.0315	×	1	×	20.4	× (-1) =	0.6
73	18:00	0.0000	×	0	×	20.0	× (-1) =	0.0
74	18:15	0.0000	×	0	×	19.7	× (-1) =	0.0
Average Event A (June 1, 2011) Impact:								0.70

Appendix H. Winter Estimation Details and Model Specification

This appendix will provide more detail on the methods employed by the evaluation team to estimate the historic winter 2012 demand impacts and forecast the DR capability of the various types of cycling strategies.

H.1 Winter Model Specification and Details

Water Heaters

The data set used to estimate the water heater model below included all quarter hours for all households with useable data.

The model used to estimate both historic winter 2011 water heater curtailment impacts and forecast water heater DR capability at a variety of temperatures is:

$$y_{k,t} = \alpha_k + \sum_{i=1}^{96} (\beta_i^{qh} \cdot qh_{i,t}) + \sum_{i=1}^{96} (\beta_i^{HDH} \cdot qh_{i,t} \cdot HDH_{k,t}) + \sum_{i=1}^{96} (\beta_i^{MA-HDH} \cdot qh_{i,t} \cdot MA_HDH_{k,t}) + \sum_{i=1}^{96} \beta_i^{c1} \cdot qh_{i,t} \cdot c_t + \sum_{i=1}^{96} \beta_i^{c2} \cdot qh_{i,t} \cdot c_t \cdot HDH_{k,t} + \sum_{r=1}^9 \beta_i^{s1} \cdot s_{r,t} + \sum_{r=1}^9 \beta_i^{s1} \cdot s_{r,t} \cdot HDH_{k,t} + \varepsilon_t$$

Where:

- $y_{k,t}$ = The average water heater demand of household k in quarter hour t .
- $qh_{i,t}$ = A dummy variable equal to one if i is equal to the quarter hour in which t happens to be. For example if quarter hour t fell in the first quarter hour of the day then $qh_{1,t}$ would equal one and $qh_{2,t}$ to $qh_{87,t}$ would all be equal to zero.
- $HDH_{k,t}$ = The heating degree hours observed in quarter hour t . For this study HDH is defined in the conventional way as 65 minus the outdoor temperature (in Fahrenheit) or zero, whichever is greater.
- $MA_HDH_{k,t}$ = Is a moving average of the heating degree hours over the 48 quarter-hourly periods immediately preceding t .
- c_t = Is a dummy variable equal to one if there is a water heater curtailment event of the taking place in quarter hour t and zero otherwise.
- $s_{r,t}$ = A group of dummy variables intended to capture the effect of snapback in the quarter hours following the end of the curtailment period. The r -th dummy is equal to one if quarter hour t is the r -th hour following the end of a curtailment event. For example if the last quarter hour of a curtailment event occurred in period $t=500$, the in period $t=501$, $s_{r=1,t=501}$ would be equal to one, whereas $s_{r=2,t=501}$ and all the snapback dummies for periods $r \neq 1$ would be equal to zero.

The parameter estimates obtained from this model (and found later in this appendix) were used to calculate the estimated impact of each of the curtailment events and the forecast capability at a variety of temperatures.

Auxiliary Heat Strips

Two subsets of the heat strip logger data were used to estimate the impacts of completely responsive and partially responsive heat strips in two regressions using the same model specification. The first data set included all of the data for non-event days, but for event days only included the data for devices that were completely responsive on that event day. The second data set included all of the data for non-event days, but for event days only included the data for devices that were partially responsive on that event day.

The estimated model for both data sets was :

$$y_{k,t} = \alpha_k + \sum_{i=1}^{96} (\beta_i^{qh} \cdot qh_{i,t}) + \sum_{i=1}^{96} (\beta_i^{HDH1} \cdot qh_{i,t} \cdot HDH_{k,t}) + \sum_{i=1}^{96} (\beta_i^{HDH2} \cdot qh_{i,t} \cdot HDH_{k,t}^{5.6}) \\ + \sum_{i=1}^{96} (\beta_i^{MA-HDH} \cdot qh_{i,t} \cdot MA_HDH_{k,t}) + \sum_{i=1}^{96} \beta_i^{c2} \cdot qh_{i,t} \cdot c_t \cdot HDH_{k,t} + \sum_{i=1}^{96} \beta_i^{c2} \cdot qh_{i,t} \cdot c_t \cdot HDH_{k,t}^{5.6} \\ + \sum_{r=1}^9 \beta_i^{s1} \cdot s_{r,t} \cdot Avg_HDH_t + \sum_{r=1}^9 \beta_i^{s2} \cdot s_{r,t} \cdot Avg_HDH_t^{5.6} + \epsilon_t$$

Where:

- $y_{k,t}$ = The average auxiliary heat strip demand of household k in quarter hour t .
- $qh_{i,t}$ = A dummy variable equal to one if i is equal to the quarter hour in which t happens to be. For example if quarter hour t fell in the first quarter hour of the day then $qh_{1,t}$ would equal one and $qh_{2,t}$ to $qh_{96,t}$ would all be equal to zero.
- $HDH_{k,t}$ = The heating degree hours observed in quarter hour t . For this study HDH is defined in the conventional way as 65 minus the outdoor temperature (in Fahrenheit) or zero, whichever is greater.
- $HDH_{k,t}^{5.6}$ = The heating degree hours observed in quarter hour t to the power of 5.6. This variable is included to control for the non-linear relationship between heat strip demand and outdoor temperature observed in the data. This particular value was chosen by re-running the regression for all exponent values between 1.1 and 7.9 (in increments of 0.1) and using the value that minimized the sum of squared residuals.
- $MA_HDH_{k,t}$ = Is a moving average of the heating degree hours over the 48 quarter-hourly periods immediately preceding t .
- Avg_HDH_t = Is the average number of HDH observed during the curtailment period of the day in which period t occurs.
- $Avg_HDH_t^{5.6}$ = Is the average number of HDH observed during the curtailment period of the day in which period t occurs, to the power of 5.6.
- c_t = Is a dummy variable equal to one if there is a water heater curtailment event of the taking place in quarter hour t and zero otherwise.
- $s_{r,t}$ = A group of dummy variables intended to capture the effect of snapback in the quarter hours following the end of the curtailment period. The r -th dummy is equal to one if quarter hour t is the r -th hour following the end of a curtailment

event. For example if the last quarter hour of a curtailment event occurred in period $t=500$, the in period $t=501$, $s_{r=1,t=501}$ would be equal to one, whereas $s_{r=2,t=501}$ and all the snapback dummies for periods $r \neq 1$ would be equal to zero.

Average household impacts were obtained by:

1. Calculating the average per device event impact for both completely responsive devices and for partially responsive devices.
2. Calculating the average per device impact for each event by weighting the impacts of completely responsive and partially responsive devices according to the percentage of devices falling in those respective categories (e.g. for Event A, average per device impact = completely responsive impact * 23% + partially responsive impact * 30%).
3. Calculating the average per household impact by multiplying the average per device impact by total number of devices divided by the total number of households.

H.2 Parameter Estimates and CDH Values Coincident with Events

Readers may use the numbers presented in this sub-section either to generate quarter-hourly specific estimates of historical impacts or quarter-hourly specific forecasts of water heater demand reduction capability.

Impacts reported in the body of this report were based on event averages, for an example of the auxiliary heat strip calculation, see Table 29 below. Note that because the regression parameter estimates are capturing a reduction in demand, the slopes presented below appear as negative numbers.

Table 24: Water Heater Demand Reduction Parameter Estimates

Quarter Hour Number	Interval Time Starting	Intercept Curtailment Dummy	HDH Slope Curtailment Dummy
25	6:00	-0.1792	-0.0003
26	6:15	-0.3019	0.0000
27	6:30	-0.3786	0.0024
28	6:45	-0.4419	0.0012
29	7:00	-0.4601	-0.0005
30	7:15	-0.4751	-0.0020
31	7:30	-0.4818	0.0001
32	7:45	-0.5652	0.0020
33	8:00	-0.2930	-0.0041
34	8:15	-0.4591	0.0002
35	8:30	-0.4120	-0.0009
36	8:45	-0.4896	0.0018
37	9:00	-0.1769	-0.0053
38	9:15	0.2126	-0.0167

Table 25: Completely Responsive Demand Reduction Parameter Estimates⁴⁴

Quarter Hour Number	Interval Time Starting	HDH Slope Curtailment Dummy	(HDH ^{5,6} Slope Curtailment Dummy)*10 ⁶
24	5:45	0.0000	0.0000
25	6:00	-0.0085	-0.0004
26	6:15	-0.0085	-0.0004
27	6:30	-0.0072	-0.0005
28	6:45	0.0020	-0.0013
29	7:00	-0.0049	-0.0010
30	7:15	-0.0142	-0.0010
31	7:30	-0.0193	-0.0008
32	7:45	-0.0194	-0.0008
33	8:00	-0.0207	-0.0008
34	8:15	-0.0209	-0.0011
35	8:30	-0.0263	-0.0008
36	8:45	-0.0194	-0.0009
37	9:00	-0.0096	-0.0019
38	9:15	0.0361	-0.0037
39	9:30	0.0000	0.0000

⁴⁴ Note that before using the "(HDH^{5,6} Slope Curtailment Dummy)*10⁶" parameter in a calculation it should be divided by 10⁶. It is presented here multiplied by 10⁶ to reduce the number of significant digits that need to be displayed.

Table 26: Partially Responsive Demand Reduction Parameter Estimates⁴⁵

Quarter Hour Number	Interval Time Starting	HDH Slope Curtailment Dummy	(HDH ^{5,6} Slope Curtailment Dummy)*10 ⁶
24	5:45	0.0000	0.0000
25	6:00	0.0324	-0.0017
26	6:15	0.0082	-0.0012
27	6:30	-0.0133	-0.0005
28	6:45	0.0176	-0.0014
29	7:00	0.0103	-0.0012
30	7:15	0.0032	-0.0011
31	7:30	-0.0029	-0.0008
32	7:45	0.0031	-0.0011
33	8:00	0.0079	-0.0012
34	8:15	-0.0068	-0.0013
35	8:30	-0.0041	-0.0013
36	8:45	-0.0043	-0.0007
37	9:00	0.0353	-0.0024
38	9:15	0.0095	-0.0023
39	9:30	0.0000	0.0000

⁴⁵ Note that before using the “(HDH^{5,6} Slope Curtailment Dummy)*10⁶” parameter in a calculation it should be divided by 10⁶. It is presented here multiplied by 10⁶ to reduce the number of significant digits that need to be displayed.

Table 27: Curtailment Event Dummy Variable

Quarter Hour Number	Interval Time Starting	Event A	Event B	Event C	Event D	Event E (Water Heater)	Event E (Aux. Heat Strip)
		4-Jan-12	13-Jan-12	13-Feb-12	5-Mar-12	6-Mar-12	6-Mar-12
24	5:45	0	0	0	0	0	0
25	6:00	0	0	1	1	0	1
26	6:15	0	0	1	1	0	1
27	6:30	1	1	1	1	0	1
28	6:45	1	1	1	1	0	1
29	7:00	1	1	1	1	1	1
30	7:15	1	1	1	1	1	1
31	7:30	1	1	1	1	1	1
32	7:45	1	1	1	1	1	1
33	8:00	1	1	1	1	1	1
34	8:15	1	1	1	1	1	1
35	8:30	1	1	1	1	1	1
36	8:45	1	1	1	1	1	1
37	9:00	1	1	0	0	0	0
38	9:15	1	1	0	0	0	0
39	9:30	0	0	0	0	0	0

Table 28: Curtailment Event Heating Degree Hours (Part 2)⁴⁶

Quarter Hour Number	Interval Time Starting	Event A	Event B	Event C	Event D	Event E
		4-Jan-12	13-Jan-12	13-Feb-12	5-Mar-12	6-Mar-12
24	5:45	49.92	40.92	43.08	27.06	40.02
25	6:00	49.92	42.00	40.92	22.02	40.92
26	6:15	49.92	42.00	40.92	22.02	40.92
27	6:30	49.92	42.00	40.92	22.02	40.92
28	6:45	49.92	42.00	40.92	22.02	40.92
29	7:00	49.92	42.00	41.46	22.98	39.93
30	7:15	49.92	42.00	41.46	22.98	39.93
31	7:30	49.92	42.00	41.46	22.98	39.93
32	7:45	49.92	42.00	41.46	22.98	39.93
33	8:00	45.06	40.02	38.04	24.00	33.00
34	8:15	45.06	40.02	38.04	24.00	33.00
35	8:30	45.06	40.02	38.04	24.00	33.00
36	8:45	45.06	40.02	38.04	24.00	33.00
37	9:00	40.02	36.96	34.08	25.08	25.98
38	9:15	40.02	36.96	34.08	25.08	25.98
39	9:30	40.02	36.96	34.08	25.08	25.98

⁴⁶ To obtain temperature in Fahrenheit, subtract the HDH number from 65.

H.3 Example Calculation

The reader may find an example calculation helpful. The calculation of the DR impact for Event A for completely responsive auxiliary heat strips is presented in Table 29, below.

Table 29: Example Calculation for Event A (January 4, 2012) Impact – Completely Responsive Auxiliary Heat Strips

Quarter Hour Number	Interval Time Starting	HDH Parameter	HDH	Curtail Dummy	(HDH ^{5,6} Parameter) * 10 ⁶	(HDH ^{5,6}) /10 ⁶	Curtail Dummy	Demand Impact (kW)							
24	5:45	0.0000	×	49.92	×	0	+	0.0000	×	3,238	×	0	×	(-1) =	0.00
25	6:00	-0.0085	×	49.92	×	0	+	-0.0004	×	3,238	×	0	×	(-1) =	0.00
26	6:15	-0.0085	×	49.92	×	0	+	-0.0004	×	3,238	×	0	×	(-1) =	0.00
27	6:30	-0.0072	×	49.92	×	1	+	-0.0005	×	3,238	×	1	×	(-1) =	1.95
28	6:45	0.0020	×	49.92	×	1	+	-0.0013	×	3,238	×	1	×	(-1) =	4.05
29	7:00	-0.0049	×	49.92	×	1	+	-0.0010	×	3,238	×	1	×	(-1) =	3.57
30	7:15	-0.0142	×	49.92	×	1	+	-0.0010	×	3,238	×	1	×	(-1) =	3.79
31	7:30	-0.0193	×	49.92	×	1	+	-0.0008	×	3,238	×	1	×	(-1) =	3.48
32	7:45	-0.0194	×	49.92	×	1	+	-0.0008	×	3,238	×	1	×	(-1) =	3.58
33	8:00	-0.0207	×	45.06	×	1	+	-0.0008	×	1,825	×	1	×	(-1) =	2.34
34	8:15	-0.0209	×	45.06	×	1	+	-0.0011	×	1,825	×	1	×	(-1) =	3.02
35	8:30	-0.0263	×	45.06	×	1	+	-0.0008	×	1,825	×	1	×	(-1) =	2.63
36	8:45	-0.0194	×	45.06	×	1	+	-0.0009	×	1,825	×	1	×	(-1) =	2.50
37	9:00	-0.0096	×	40.02	×	1	+	-0.0019	×	939	×	1	×	(-1) =	2.12
38	9:15	0.0361	×	40.02	×	1	+	-0.0037	×	939	×	1	×	(-1) =	1.99
39	9:30	0.0000	×	40.02	×	0	+	0.0000	×	939	×	0	×	(-1) =	0.00
Average Event A Completely Responsive Aux. Heat Strip Impact															2.92

Having obtained the average impact for the completely responsive heat strips, the per household average impact may be calculated using the following inputs:

- Average impact for partially responsive heat strips on Event A: 2.44 kW
- Percent of auxiliary heat strips that are completely responsive on Event A: 23%
- Percent of auxiliary heat strips that are partially responsive on Event A: 30%
- Number of installations per household: 1.05⁴⁷

$$\text{Average per household impact}^{48} (\text{kW}) = 2.92 \times 23\% + 2.44 \times 30\% = 1.46$$

⁴⁷ For Events A and B only. For Events C, D and E this is 1.06.

⁴⁸ Note that as written the result of this equation is in fact 1.47 rather than 1.46. The deviation is the result of rounding on the input numbers.

Appendix I. Summer Device Responsiveness Plots

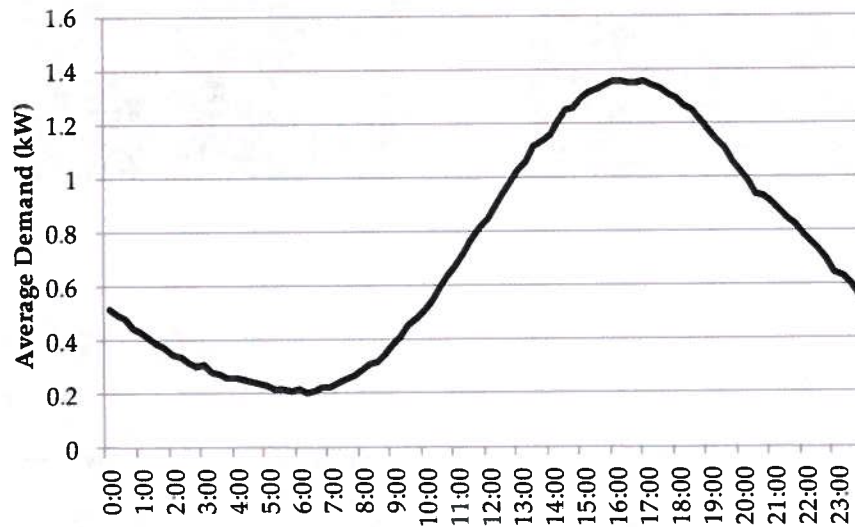
This appendix includes plots of the average indoor temperature and average demand of all A/C units, for each event, split according to whether that unit was deemed to have successfully curtailed or not. The threshold criterion used to make the determination of a successful curtailment is shown for each set of plots, and is one of the following: 0%, 15% or 25%. A 0% threshold means simply that a device is considered to have successfully curtailed if the average level of demand during the event hour is not higher than it was in the prior hour (as defined in the main body of the text above).

Note that the data for devices which were not in operation before or after the event were not included in the plot. This includes devices that were not in operation for the entire time, as well as those which were not in operation prior to the event, but were afterwards, or were in operation prior to the event but not afterwards.

As noted in the text above, the threshold criterion was applied when comparing the demand in the hour before an event occurred (the “prior hour”) to the average demand over the hour that took place after the first half hour of the event (the “event hour”). The fact that this comparison was made between the prior hour and the event hour (rather than the event hour and the hour following the event) is why the “Comparator Period” in the tables accompanying each set of plots is indicated to be “Prior Hour”. The observant reader will note that in general the lines representing the demand or temperature of A/C units that were determined to have failed to curtail (grey) is more jagged than the lines representing the demand or temperature of units where curtailment was determined to have been successful (black). This is simply a function of the smoothing effects of averaging over large numbers – the black line will nearly always be smoother than the grey line simply because it is the average of a much larger number of units than the grey line.

Caution must be exercised in examining these plots, particularly those of demand. Electricity demand data is notoriously “noisy” –particularly as the granularity of the data increases. Likewise in most cases there will be considerably fewer units considered to have failed to curtail than to have successfully curtailed. What this means is that plots of demand of devices that were non responsive will tend to be more jagged than the plots of demand for devices that were responsive and may not always conform to the typically expected summer day load profile. Most readers will be familiar with the shape of the typical residential summer load shape, such as the one shown in Figure 55 below. This is the average demand of all units for which data exists in each fifteen minute interval of all non-event weekday.

Figure 55: Typical Average Summer Residential Load Shape



Source: Navigant Logger Data and Analysis

The reader must bear in mind, however, when comparing the load profile of the non-responsive devices to the standard load profile, that the standard load profile is an average of a very large number of contributing units. In the case of Figure 55 above, it is an average load shape of 122 devices over 56 days.

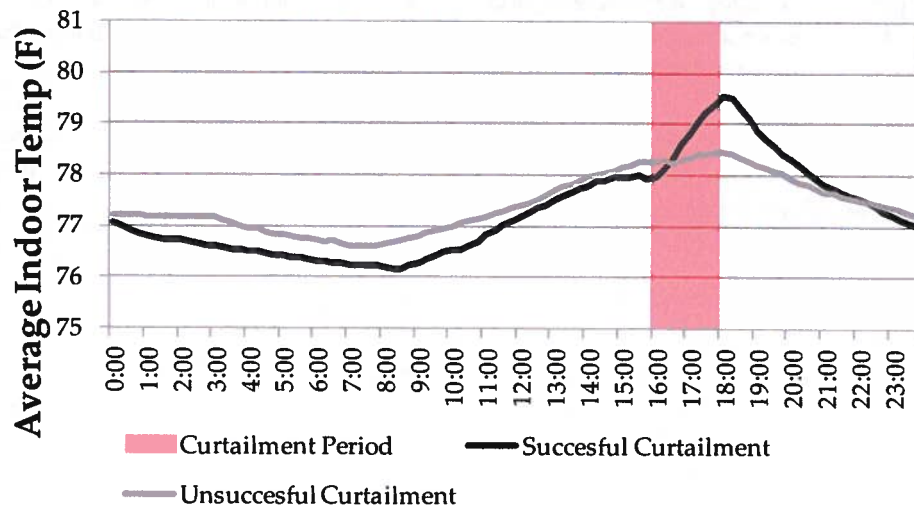
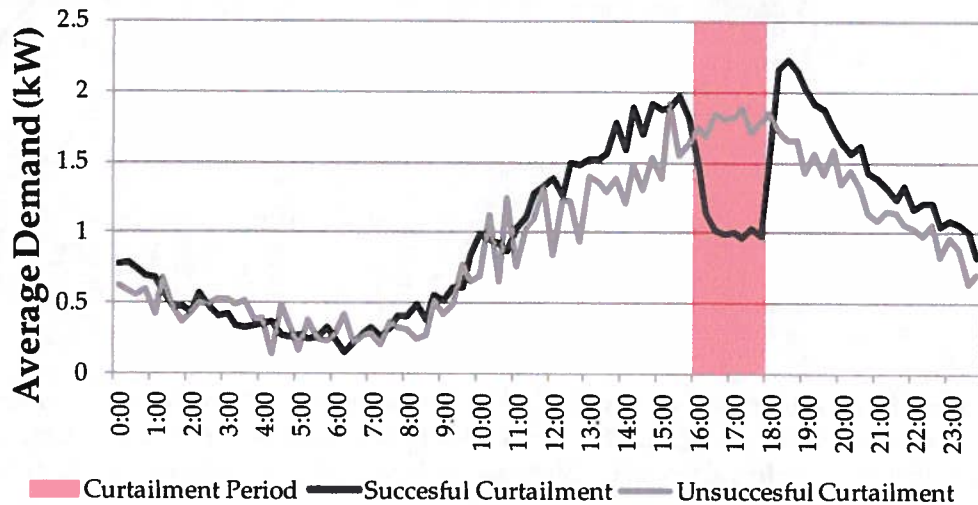
The load shapes of non-responsive devices are the average demand of ten to fifteen percent as many individual units, on a single day. Thus, significant deviations from the typical load shape (e.g. a flatter peak than typical) should be expected.

All of the above is intended to emphasize that when examining the plots in this Appendix the evaluation team believes that false positives are most easily detected in observing the change in indoor temperature data rather than the demand data.

Event A – 0% Threshold

Event Date	1-Jun-11	Curtailment Strategy	50%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	91	# Failed Curtail	11
# On During But Not Before Event*	6	# On During But Not After Event*	3
# Not On During Event*	10	Avg. Temp (F) At System Peak	98

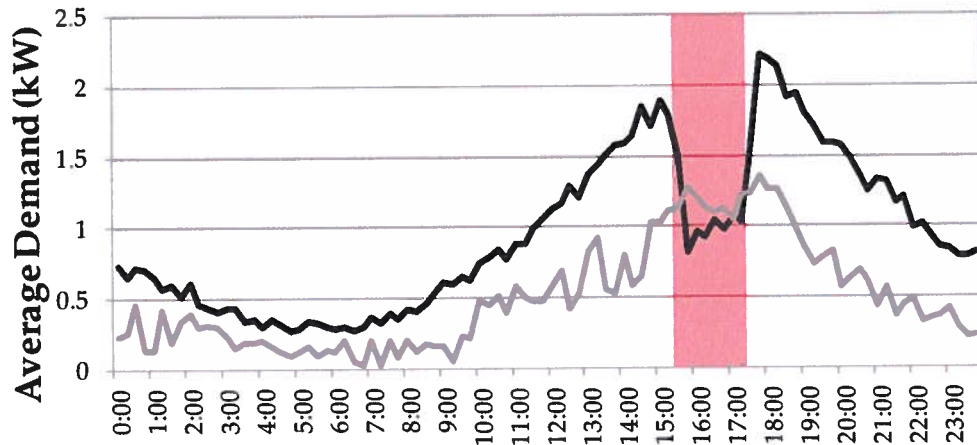
*Not shown in graph



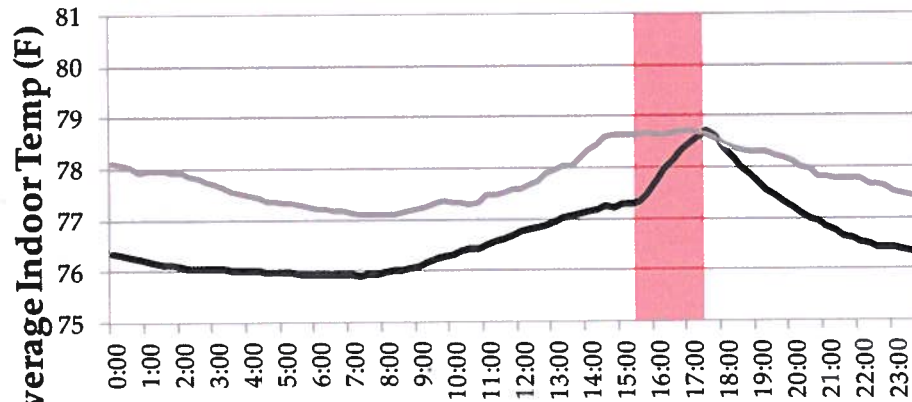
Event B – 0% Threshold

Event Date	9-Jun-11	Curtailment Strategy	50%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	91	# Failed Curtail	10
# On During But Not Before Event*	5	# On During But Not After Event*	0
# Not On During Event*	14	Avg. Temp (F) At System Peak	93

*Not shown in graph



█ Curtailment Period — Successful Curtailment — Unsuccessful Curtailment

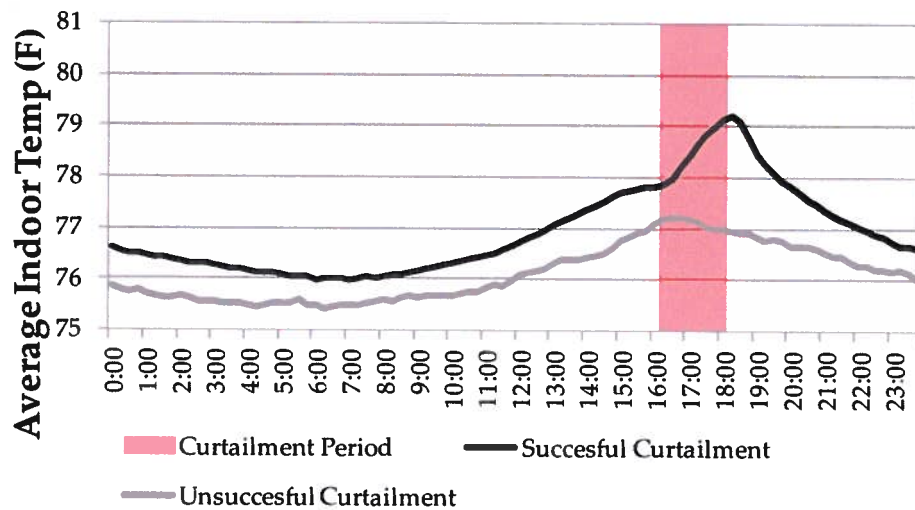
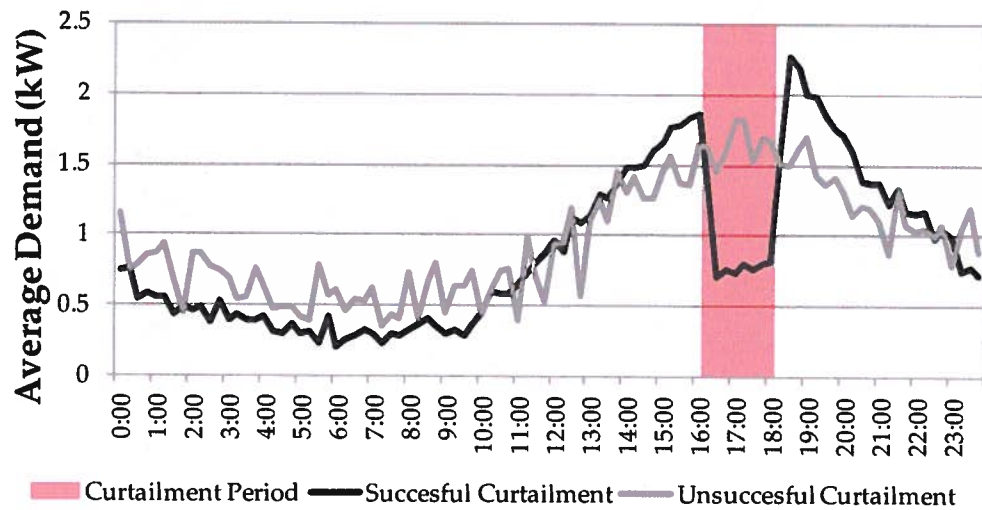


█ Curtailment Period — Successful Curtailment — Unsuccessful Curtailment

Event C – 0% Threshold

Event Date	22-Jun-11	Curtailment Strategy	65%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	88	# Failed Curtail	11
# On During But Not Before Event*	6	# On During But Not After Event*	1
# Not On During Event*	13	Avg. Temp (F) At System Peak	95

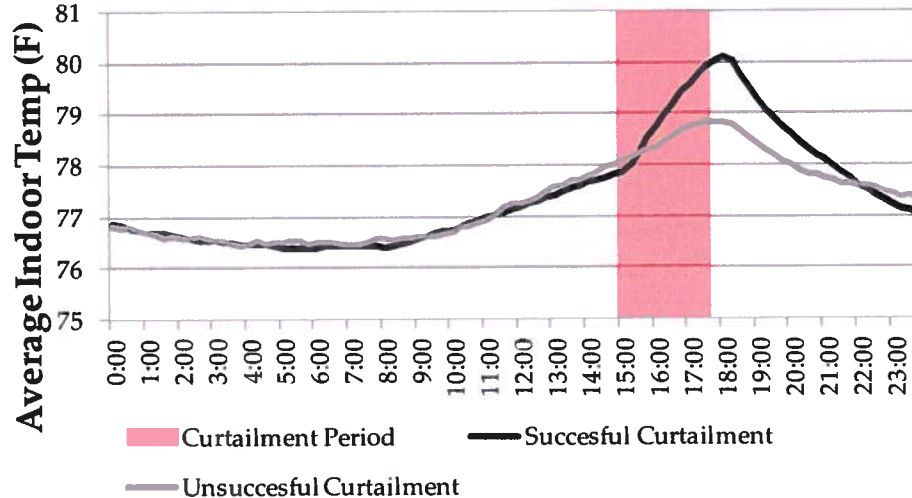
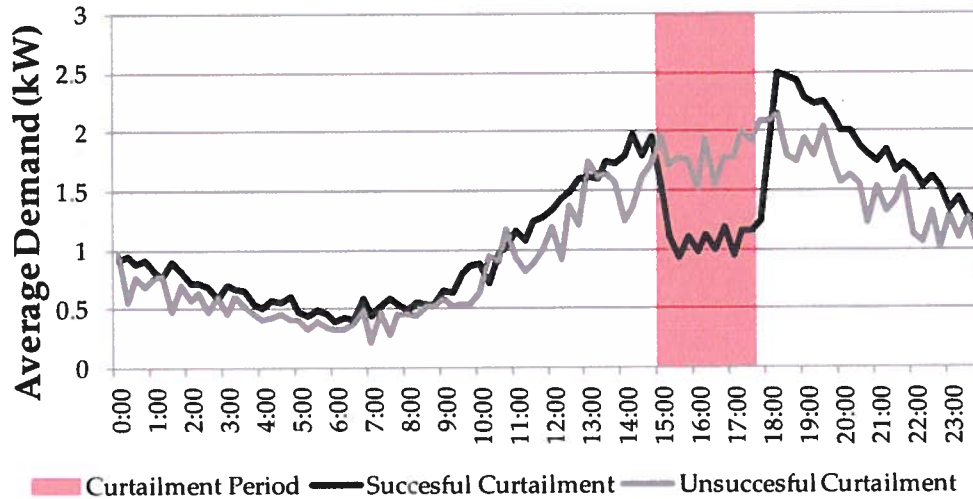
*Not shown in graph



Event D – 0% Threshold

Event Date	12-Jul-11	Curtailment Strategy	50%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	85	# Failed Curtail	16
# On During But Not Before Event*	8	# On During But Not After Event*	0
# Not On During Event*	7	Avg. Temp (F) At System Peak	94

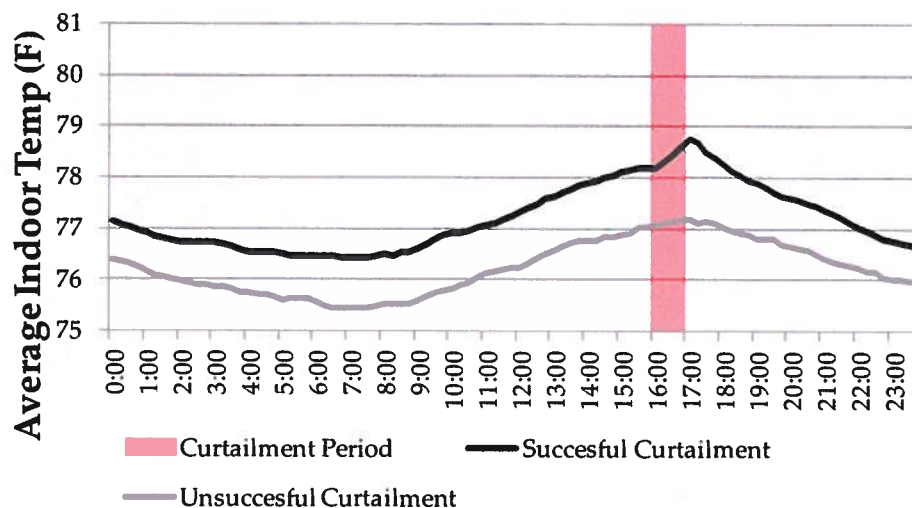
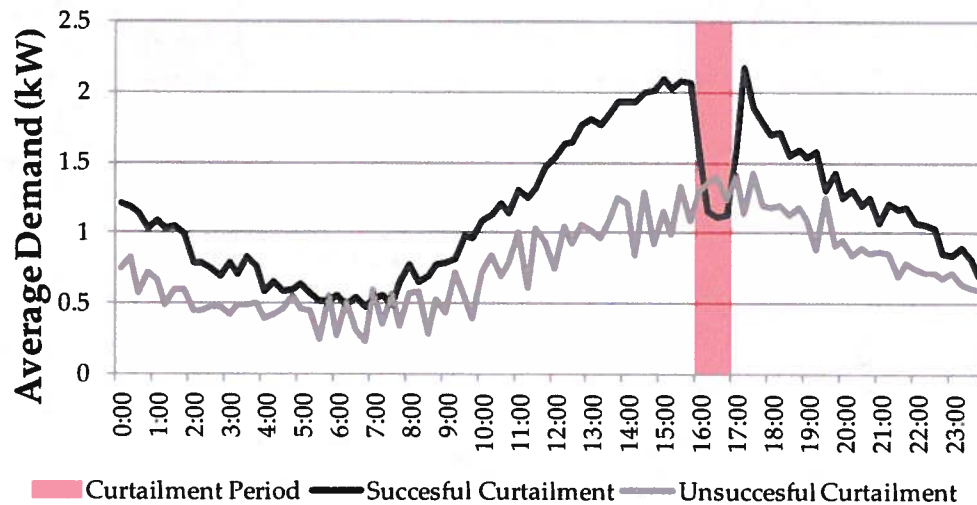
*Not shown in graph



Event E – 0% Threshold

Event Date	13-Jul-11	Curtailment Strategy	50%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	93	# Failed Curtail	8
# On During But Not Before Event*	0	# On During But Not After Event*	2
# Not On During Event*	8	Avg. Temp (F) At System Peak	98

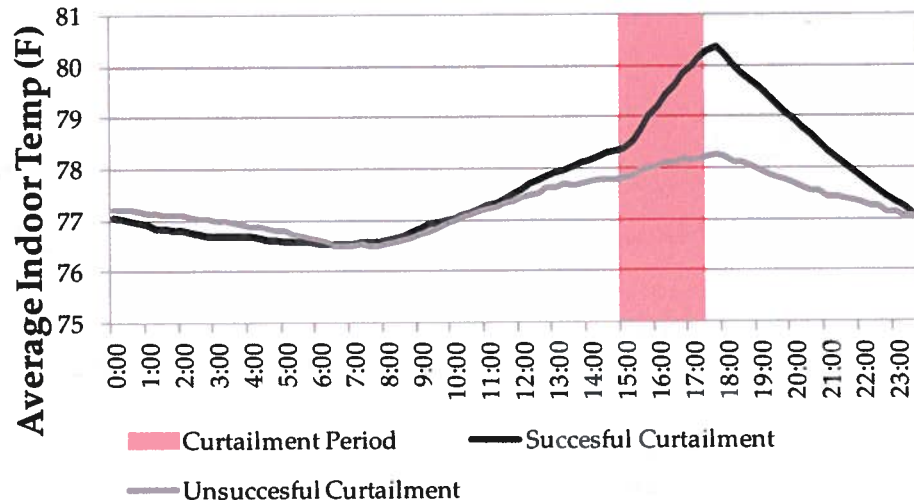
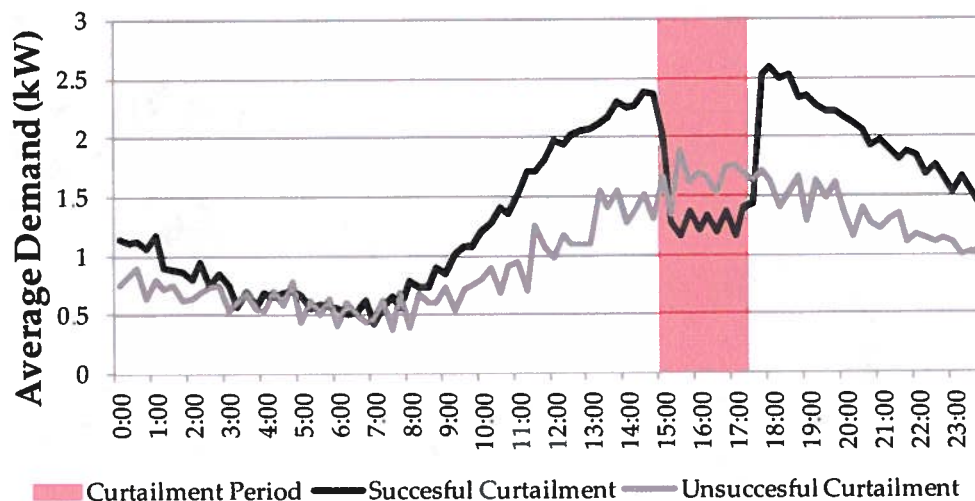
*Not shown in graph



Event F – 0% Threshold

Event Date	22-Jul-11	Curtailment Strategy	50%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	83	# Failed Curtail	12
# On During But Not Before Event*	5	# On During But Not After Event*	1
# Not On During Event*	11	Avg. Temp (F) At System Peak	95

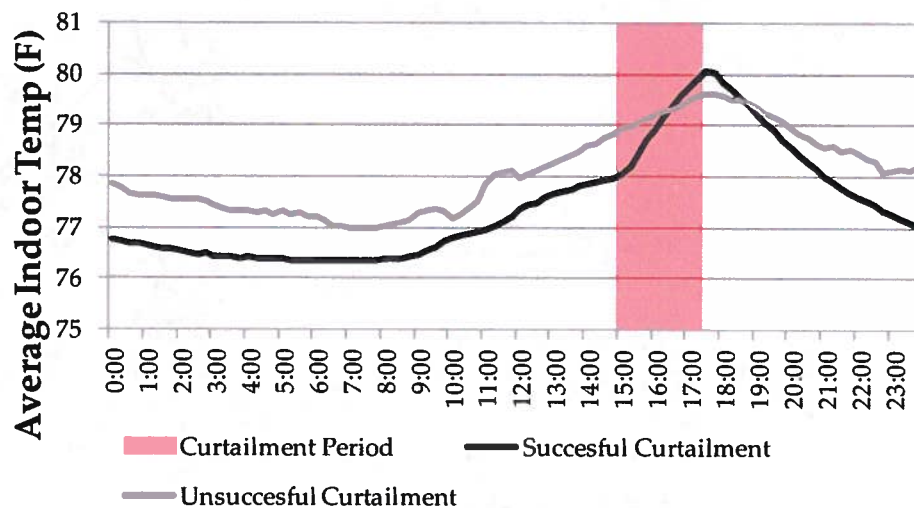
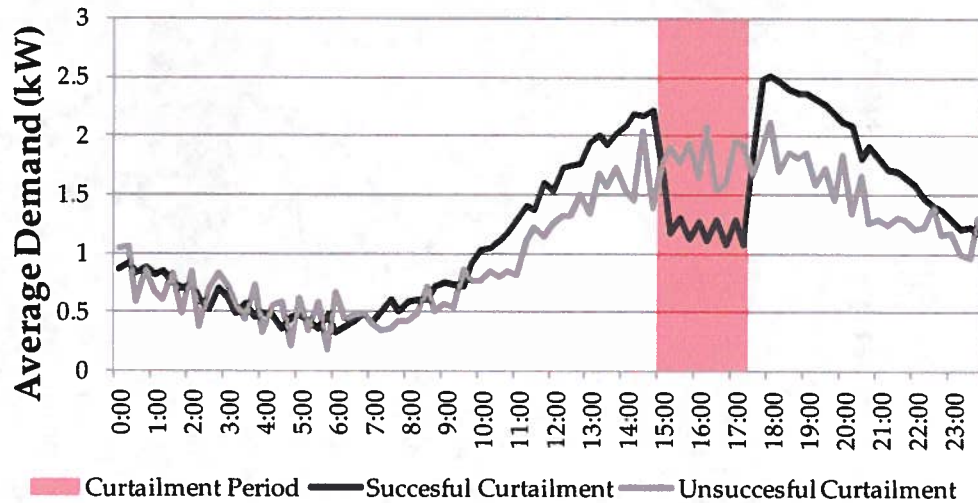
*Not shown in graph



Event G – 0% Threshold

Event Date	29-Jul-11	Curtailment Strategy	50%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	89	# Failed Curtail	10
# On During But Not Before Event*	6	# On During But Not After Event*	0
# Not On During Event*	7	Avg. Temp (F) At System Peak	100

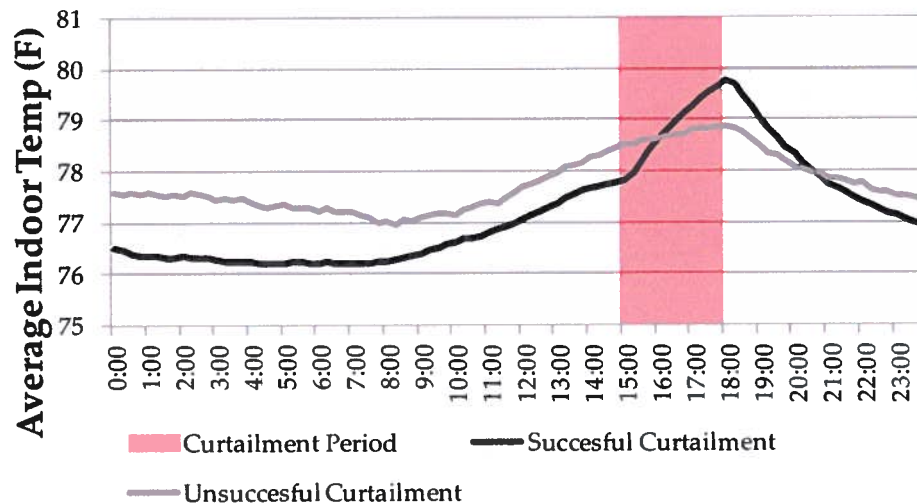
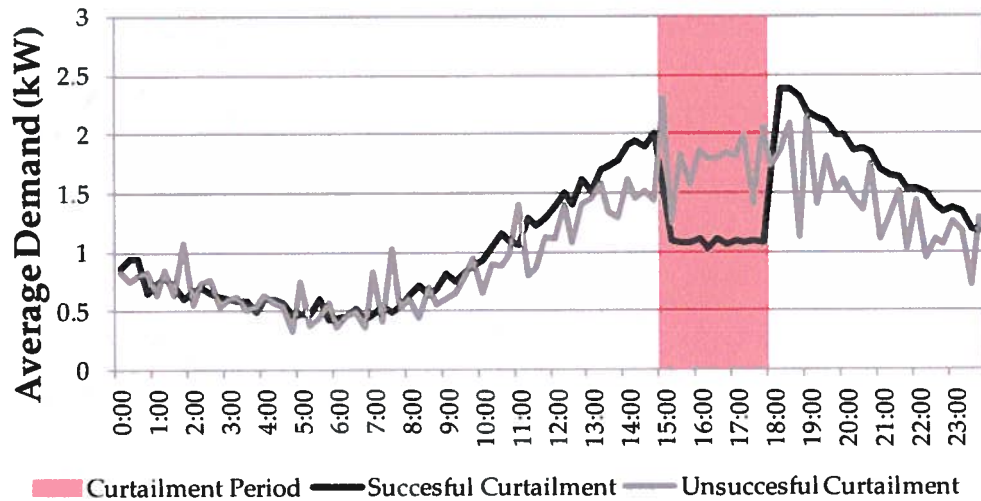
*Not shown in graph



Event H - 0% Threshold

Event Date	4-Aug-11	Curtailment Strategy	50%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	84	# Failed Curtail	15
# On During But Not Before Event*	3	# On During But Not After Event*	2
# Not On During Event*	6	Avg. Temp (F) At System Peak	100

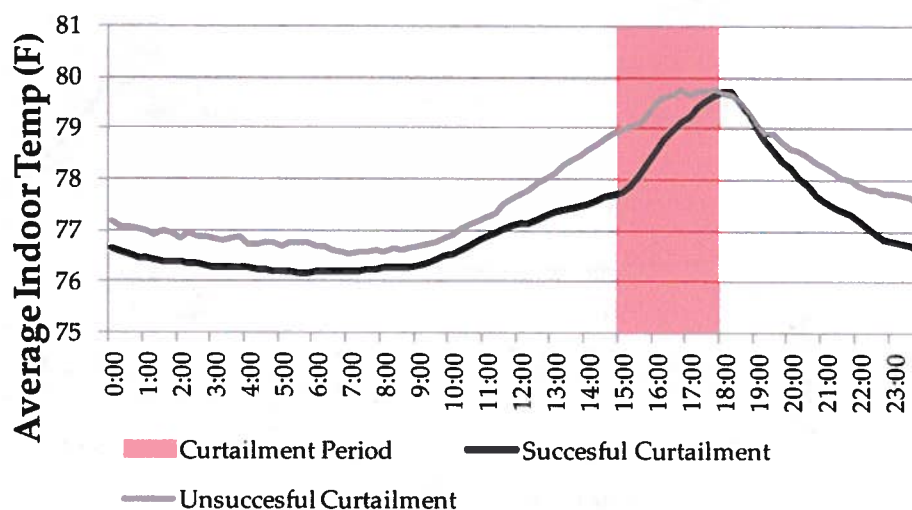
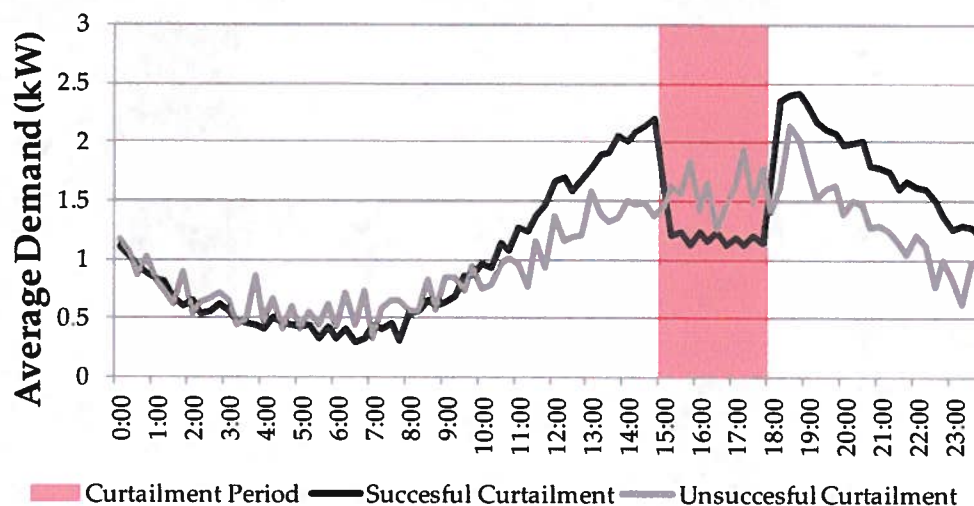
*Not shown in graph



Event I – 0% Threshold

Event Date	8-Aug-11	Curtailment Strategy	50%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	72	# Failed Curtail	16
# On During But Not Before Event*	10	# On During But Not After Event*	4
# Not On During Event*	6	Avg. Temp (F) At System Peak	95

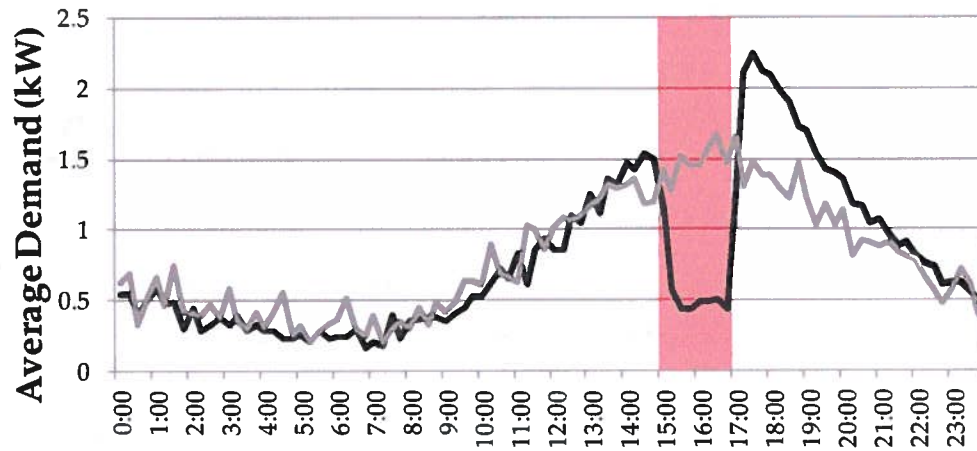
*Not shown in graph



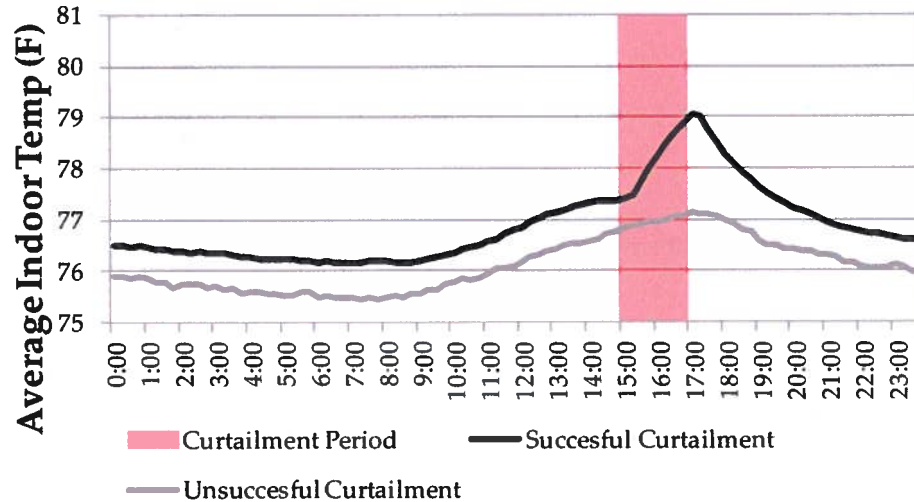
Event J – 0% Threshold

Event Date	22-Aug-11	Curtailment Strategy	75%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	71	# Failed Curtail	14
# On During But Not Before Event*	11	# On During But Not After Event*	2
# Not On During Event*	10	Avg. Temp (F) At System Peak	96

*Not shown in graph



█ Curtailment Period — Successful Curtailment — Unsuccessful Curtailment

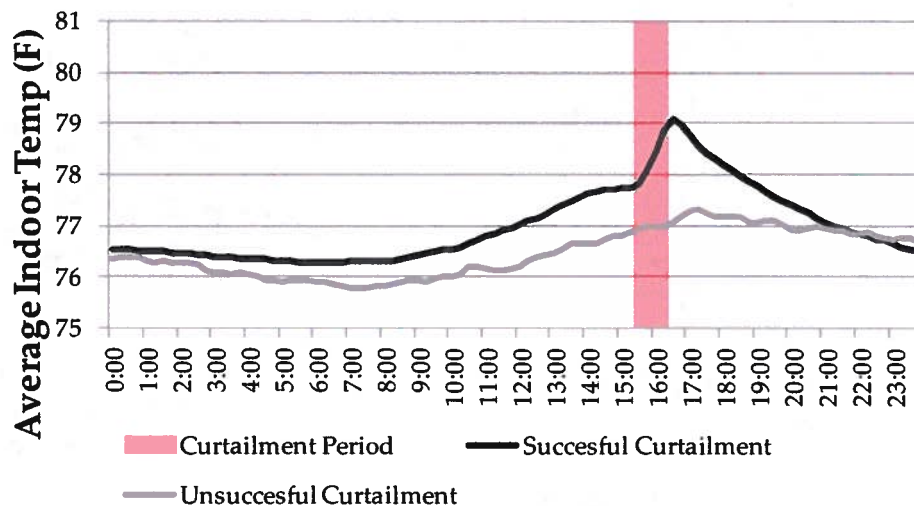
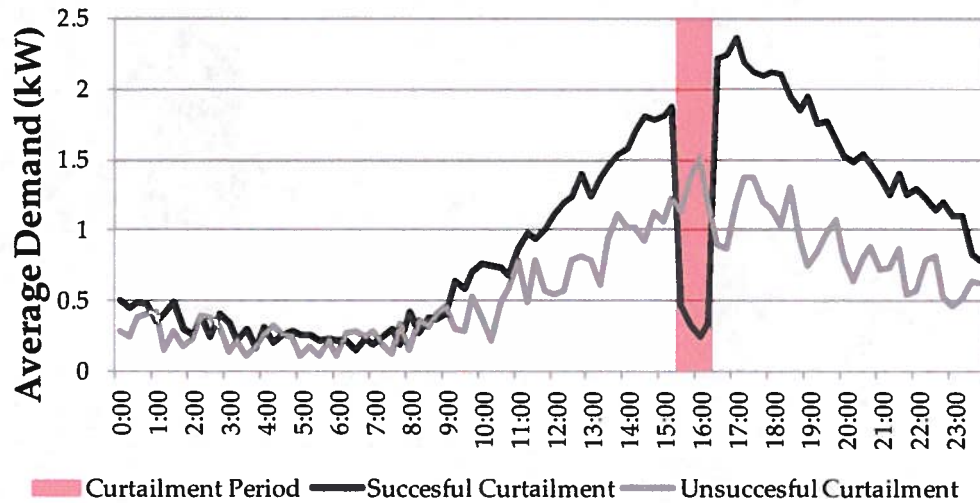


█ Curtailment Period — Successful Curtailment — Unsuccessful Curtailment

Event K – 0% Threshold

Event Date	25-Aug-11	Curtailment Strategy	100%
Threshold	0%	Comparator Period	Prior Hour
# Successful Curtail	74	# Failed Curtail	14
# On During But Not Before Event*	7	# On During But Not After Event*	1
# Not On During Event*	12	Avg. Temp (F) At System Peak	90

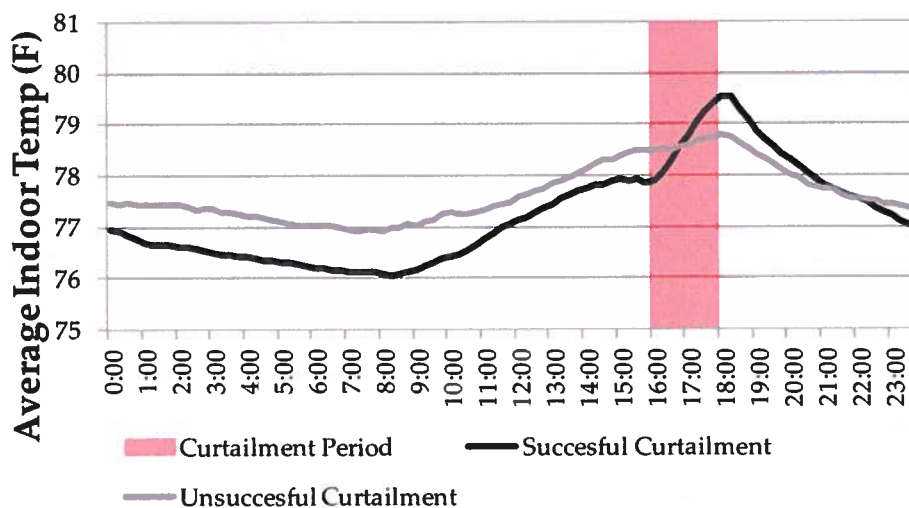
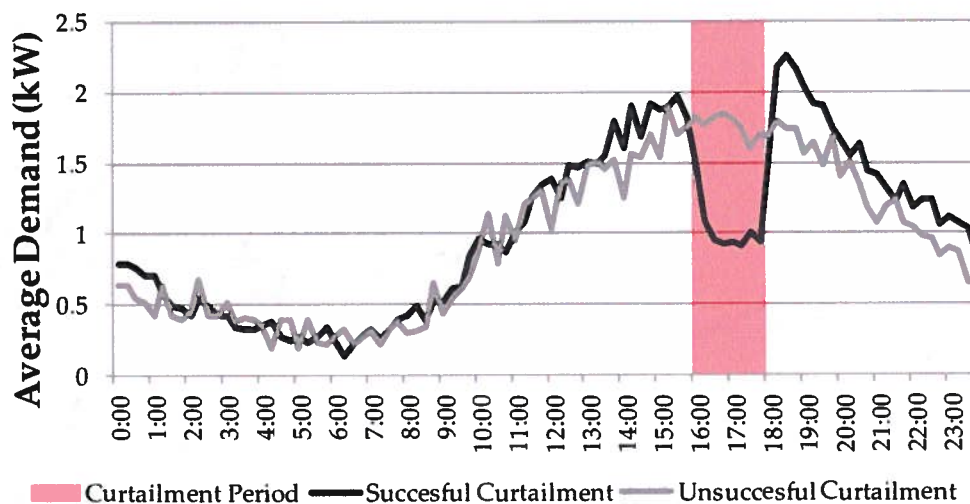
*Not shown in graph



Event A – 15% Threshold

Event Date	1-Jun-11	Curtailment Strategy	50%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	84	# Failed Curtail	18
# On During But Not Before Event*	6	# On During But Not After Event*	3
# Not On During Event*	10	Avg. Temp (F) At System Peak	98

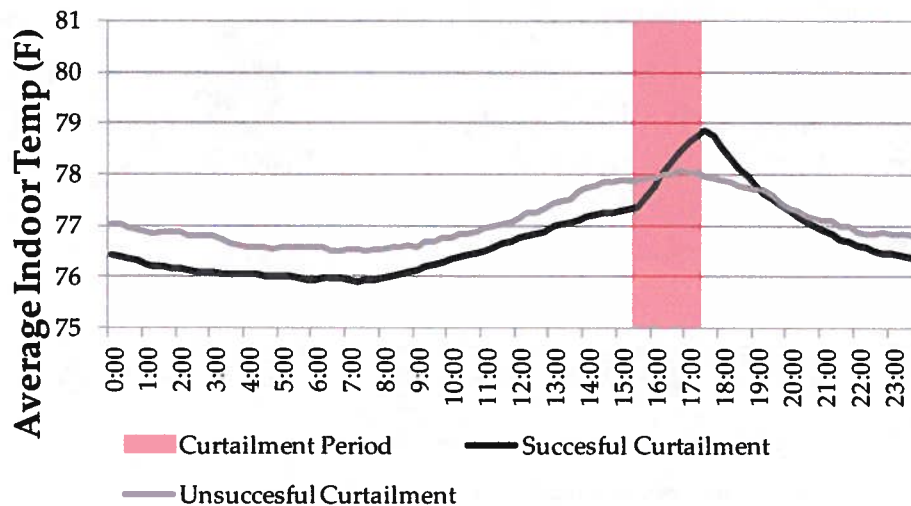
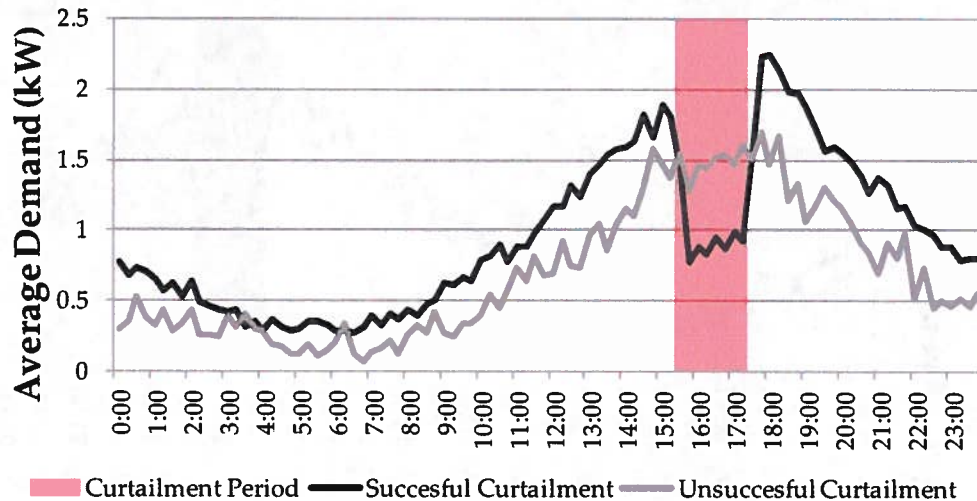
*Not shown in graph



Event B – 15% Threshold

Event Date	9-Jun-11	Curtailment Strategy	50%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	82	# Failed Curtail	19
# On During But Not Before Event*	5	# On During But Not After Event*	0
# Not On During Event*	14	Avg. Temp (F) At System Peak	93

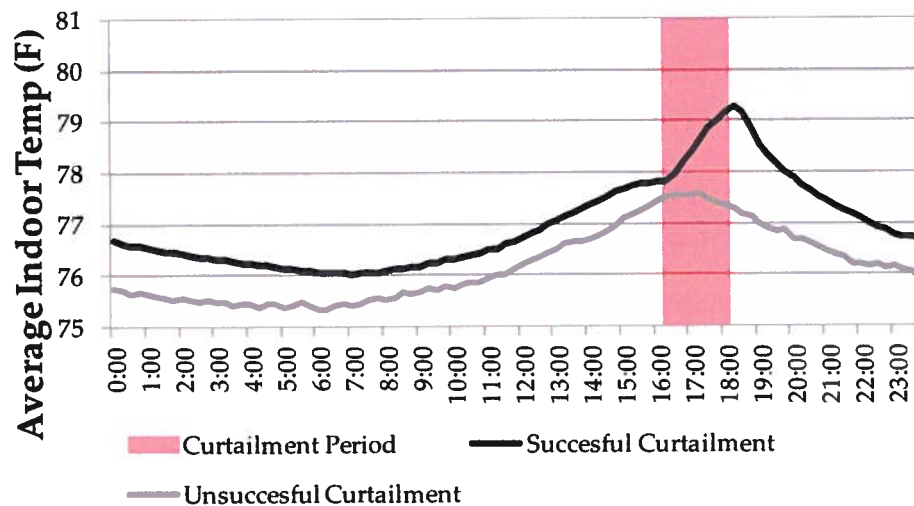
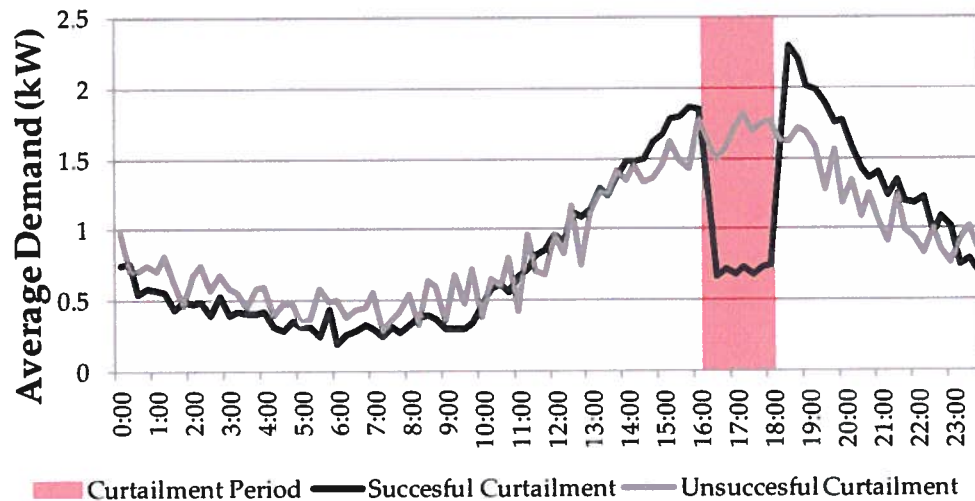
*Not shown in graph



Event C – 15% Threshold

Event Date	22-Jun-11	Curtailment Strategy	65%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	84	# Failed Curtail	15
# On During But Not Before Event*	6	# On During But Not After Event*	1
# Not On During Event*	13	Avg. Temp (F) At System Peak	95

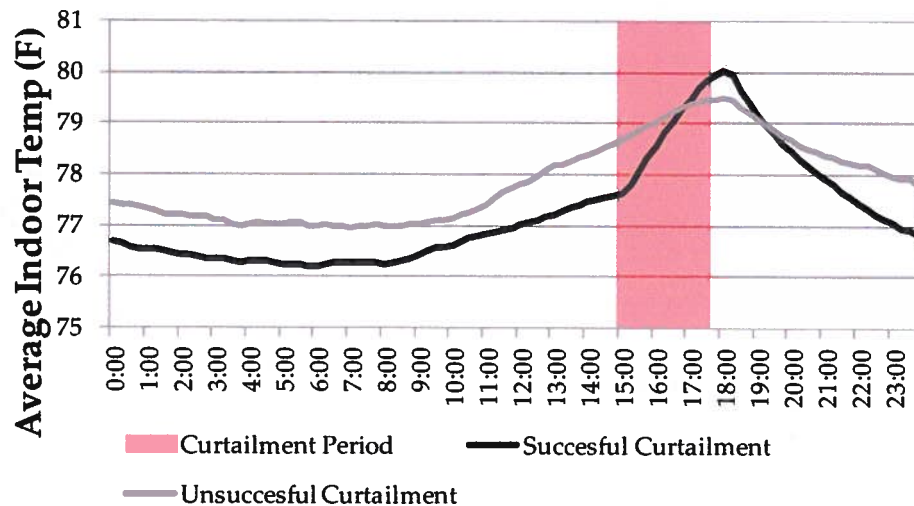
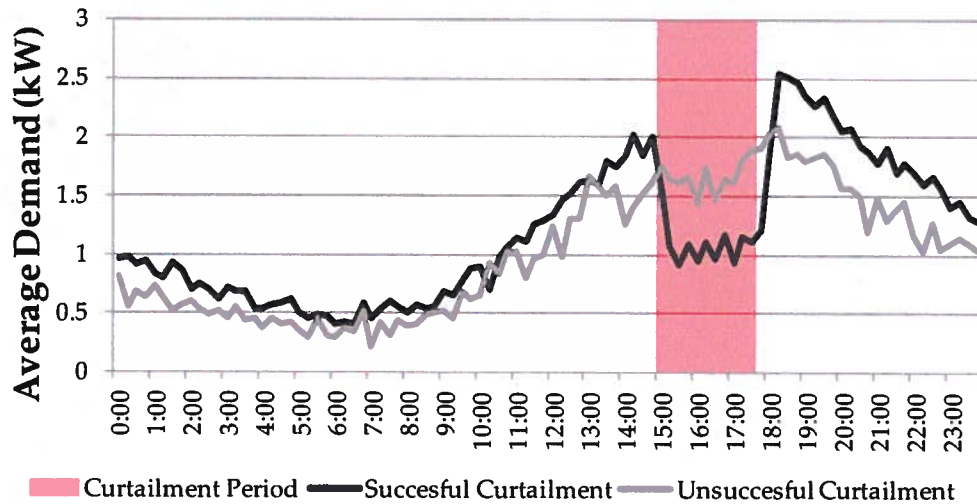
*Not shown in graph



Event D – 15% Threshold

Event Date	12-Jul-11	Curtailment Strategy	50%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	78	# Failed Curtail	23
# On During But Not Before Event*	8	# On During But Not After Event*	0
# Not On During Event*	7	Avg. Temp (F) At System Peak	94

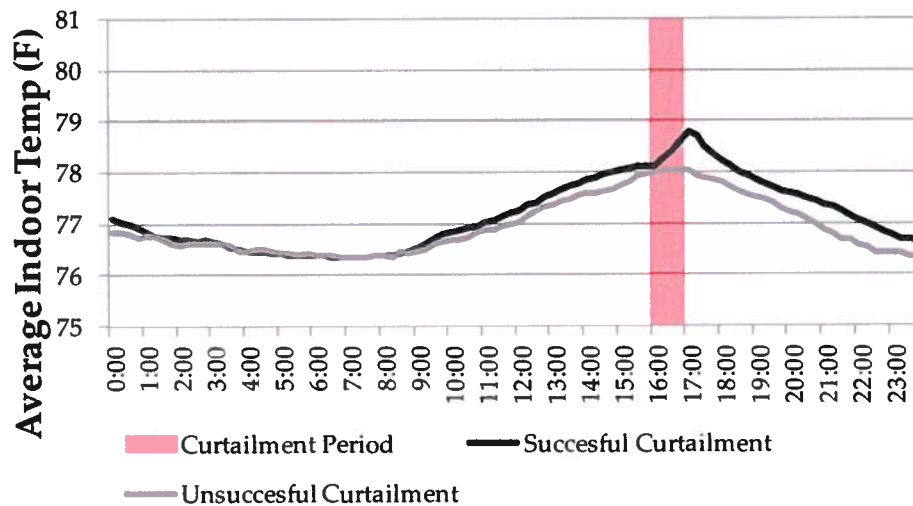
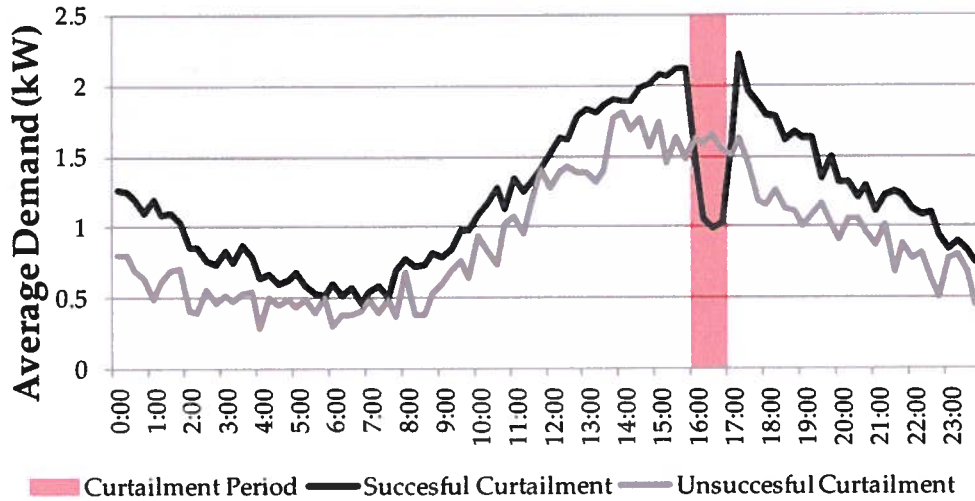
*Not shown in graph



Event E – 15% Threshold

Event Date	13-Jul-11	Curtailment Strategy	50%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	80	# Failed Curtail	21
# On During But Not Before Event*	0	# On During But Not After Event*	2
# Not On During Event*	8	Avg. Temp (F) At System Peak	98

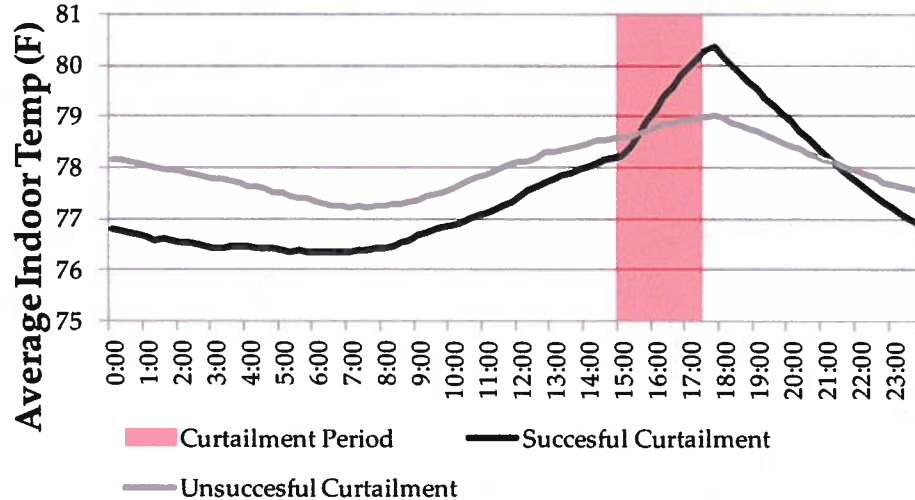
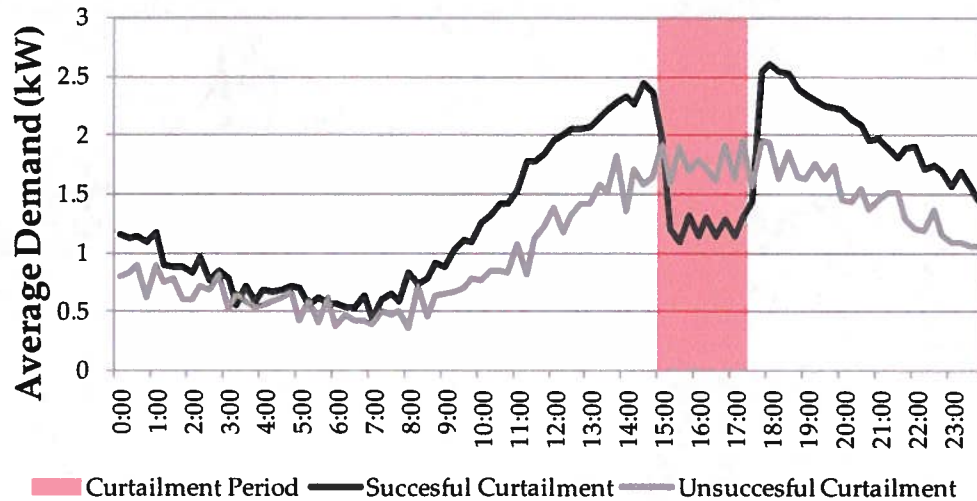
*Not shown in graph



Event F – 15% Threshold

Event Date	22-Jul-11	Curtailment Strategy	50%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	76	# Failed Curtail	19
# On During But Not Before Event*	5	# On During But Not After Event*	1
# Not On During Event*	11	Avg. Temp (F) At System Peak	95

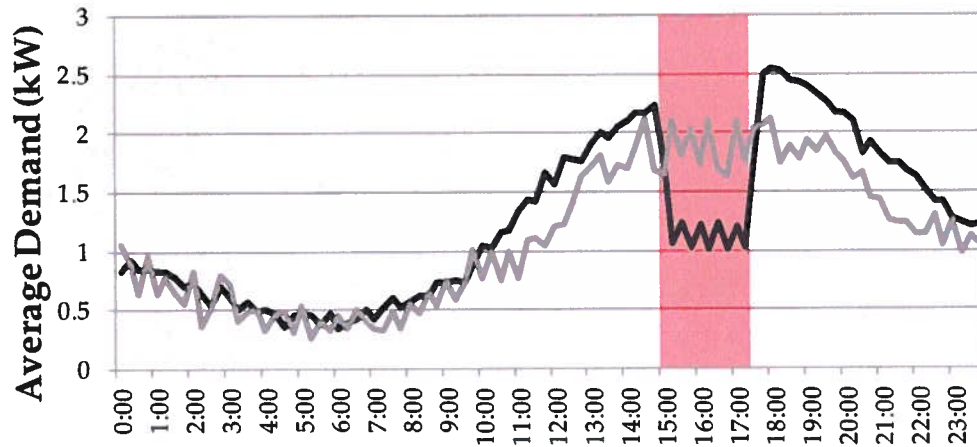
*Not shown in graph



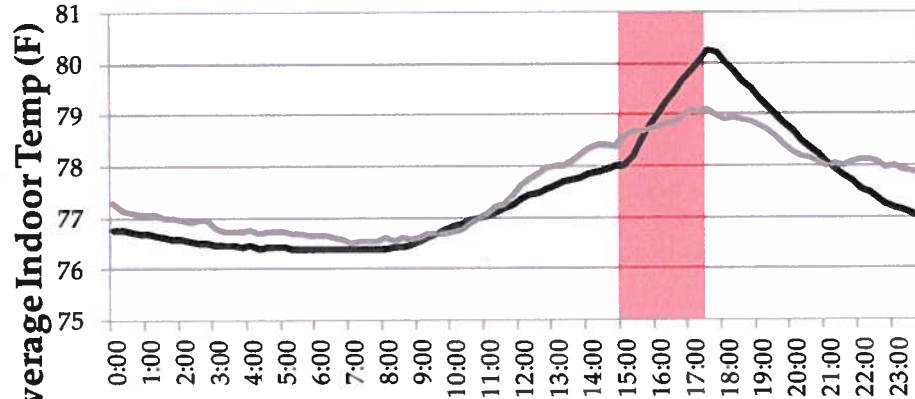
Event G – 15% Threshold

Event Date	29-Jul-11	Curtailment Strategy	50%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	82	# Failed Curtail	17
# On During But Not Before Event*	6	# On During But Not After Event*	0
# Not On During Event*	7	Avg. Temp (F) At System Peak	100

*Not shown in graph



■ Curtailment Period — Successful Curtailment — Unsuccessful Curtailment

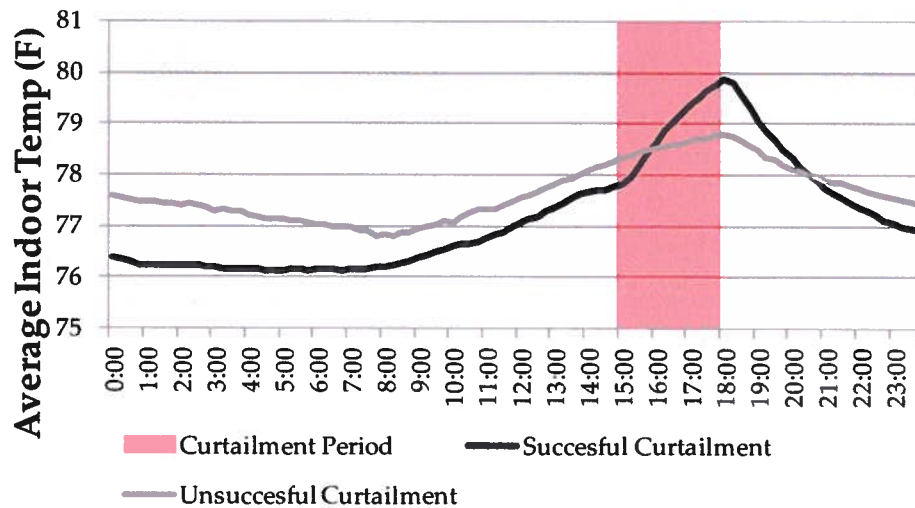
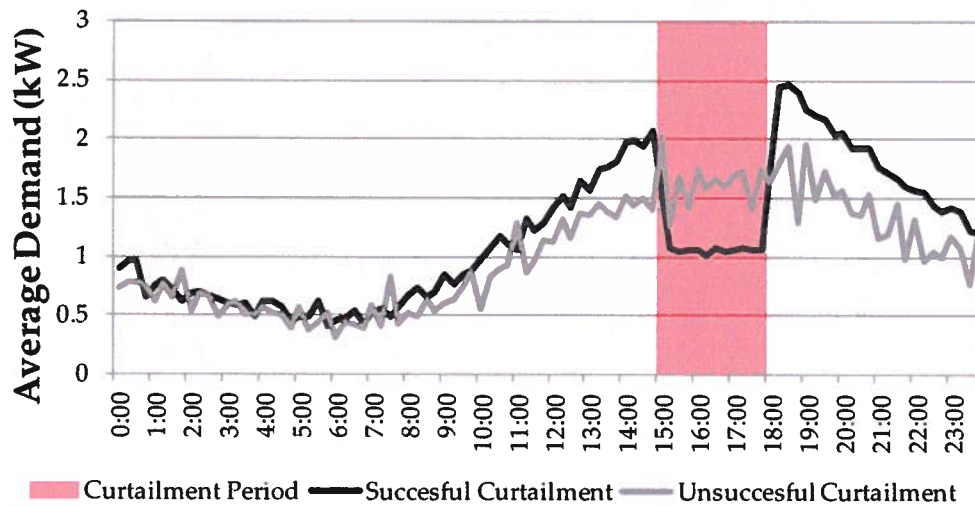


■ Curtailment Period — Successful Curtailment — Unsuccessful Curtailment

Event H – 15% Threshold

Event Date	4-Aug-11	Curtailment Strategy	50%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	77	# Failed Curtail	22
# On During But Not Before Event*	3	# On During But Not After Event*	2
# Not On During Event*	6	Avg. Temp (F) At System Peak	100

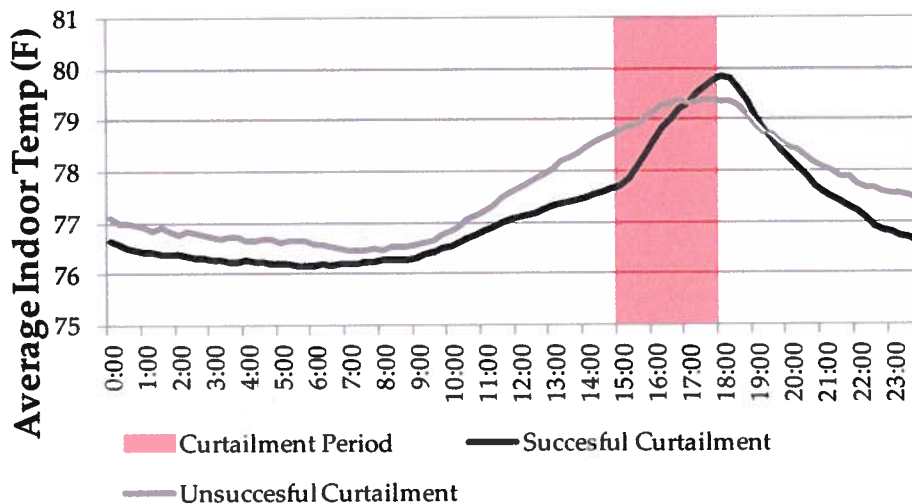
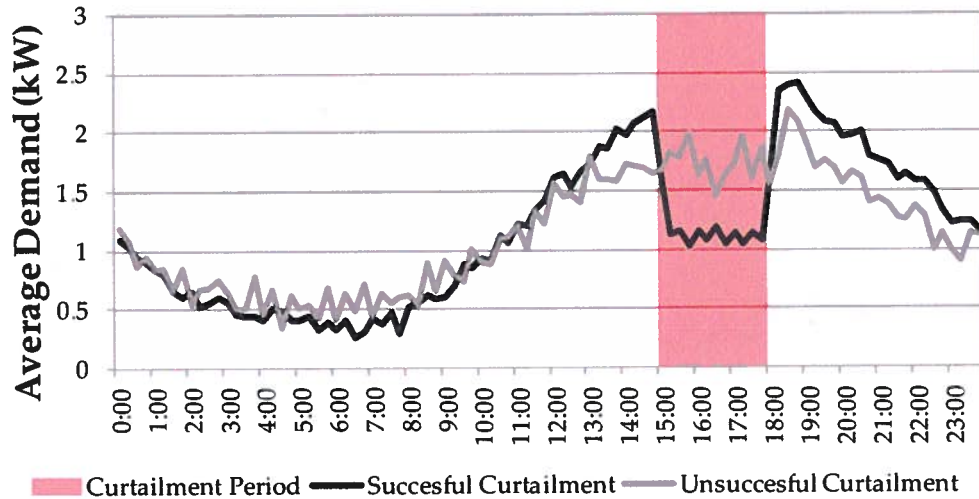
*Not shown in graph



Event I – 15% Threshold

Event Date	8-Aug-11	Curtailment Strategy	50%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	68	# Failed Curtail	20
# On During But Not Before Event*	10	# On During But Not After Event*	4
# Not On During Event*	6	Avg. Temp (F) At System Peak	95

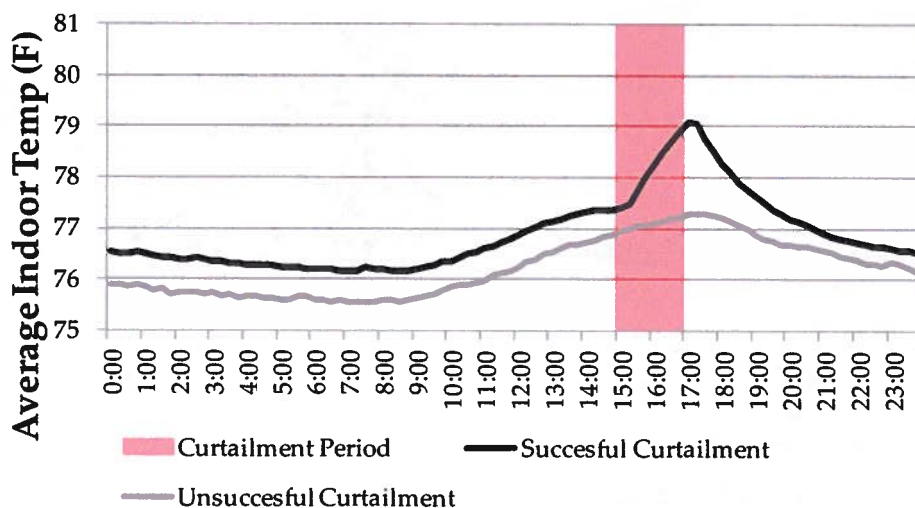
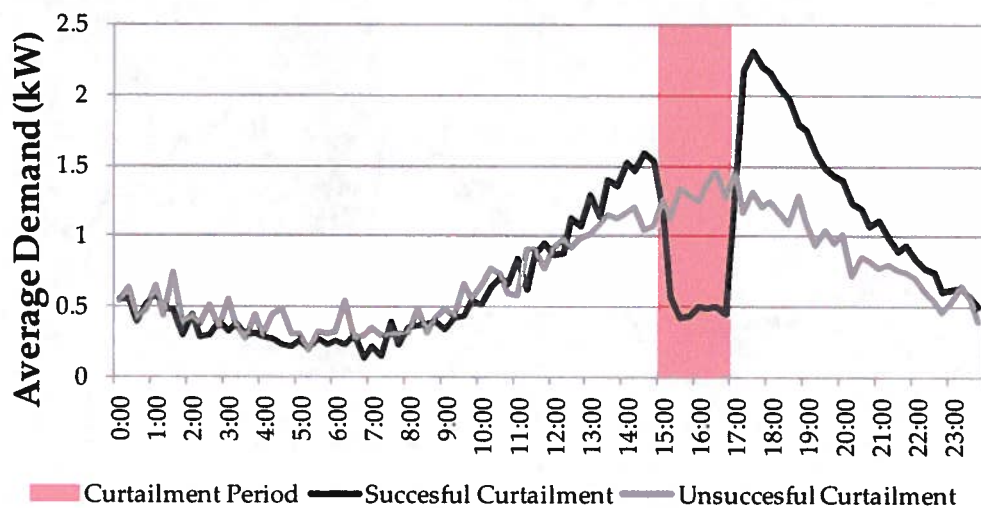
*Not shown in graph



Event J – 15% Threshold

Event Date	22-Aug-11	Curtailment Strategy	75%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	68	# Failed Curtail	17
# On During But Not Before Event*	11	# On During But Not After Event*	2
# Not On During Event*	10	Avg. Temp (F) At System Peak	96

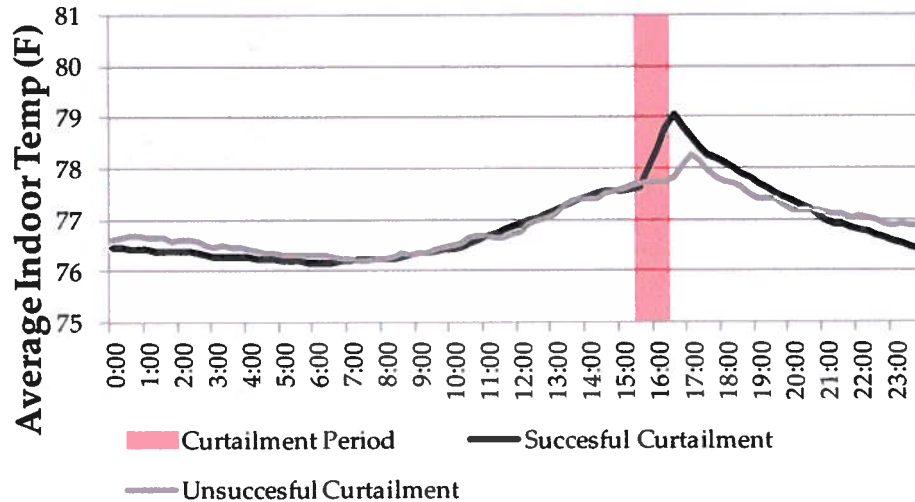
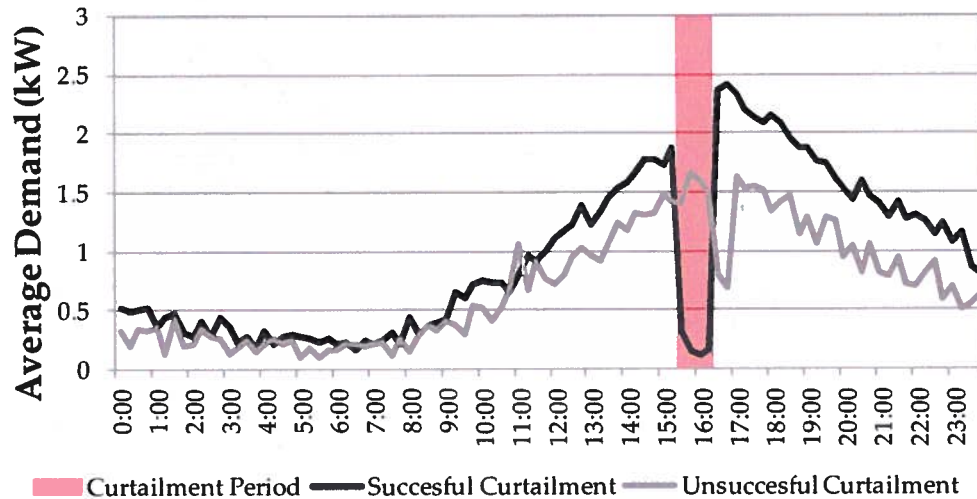
*Not shown in graph



Event K – 15% Threshold

Event Date	25-Aug-11	Curtailment Strategy	100%
Threshold	15%	Comparator Period	Prior Hour
# Successful Curtail	68	# Failed Curtail	20
# On During But Not Before Event*	7	# On During But Not After Event*	1
# Not On During Event*	12	Avg. Temp (F) At System Peak	90

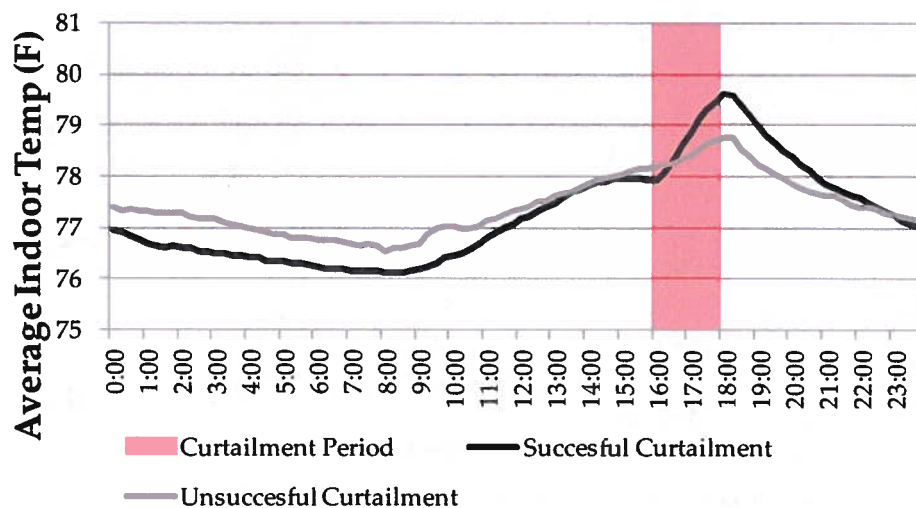
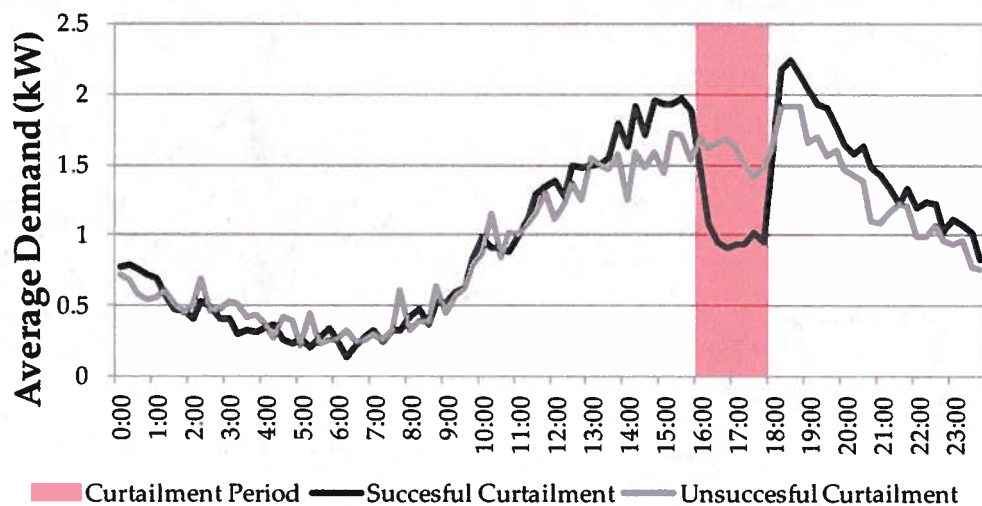
*Not shown in graph



Event A – 25% Threshold

Event Date	1-Jun-11	Curtailment Strategy	50%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	79	# Failed Curtail	23
# On During But Not Before Event*	6	# On During But Not After Event*	3
# Not On During Event*	10	Avg. Temp (F) At System Peak	98

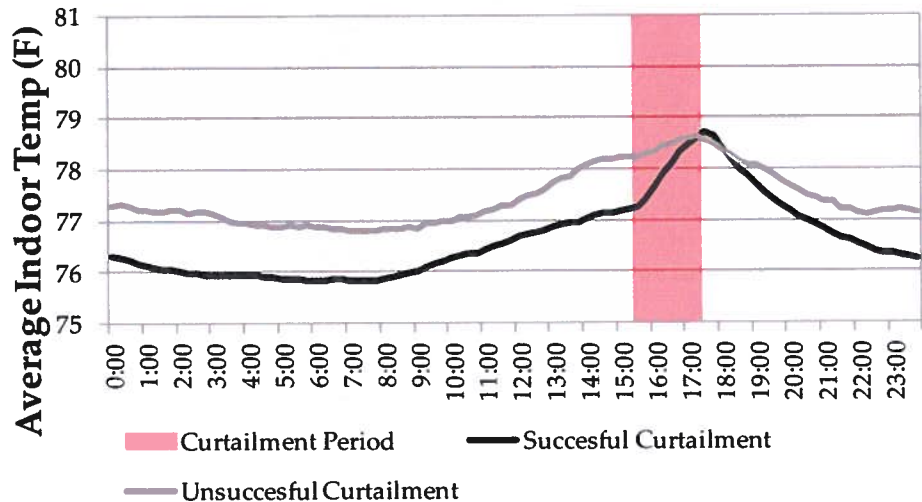
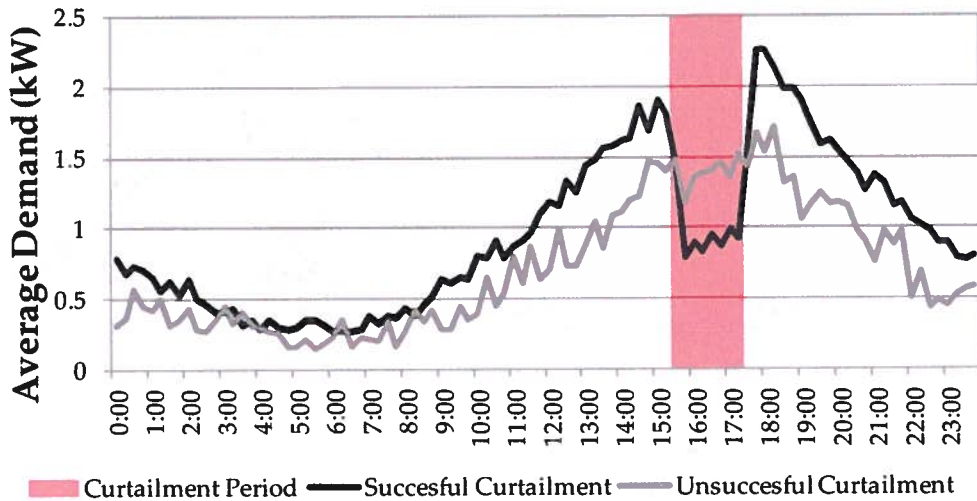
*Not shown in graph



Event B – 25% Threshold

Event Date	9-Jun-11	Curtailment Strategy	50%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	79	# Failed Curtail	22
# On During But Not Before Event*	5	# On During But Not After Event*	0
# Not On During Event*	14	Avg. Temp (F) At System Peak	93

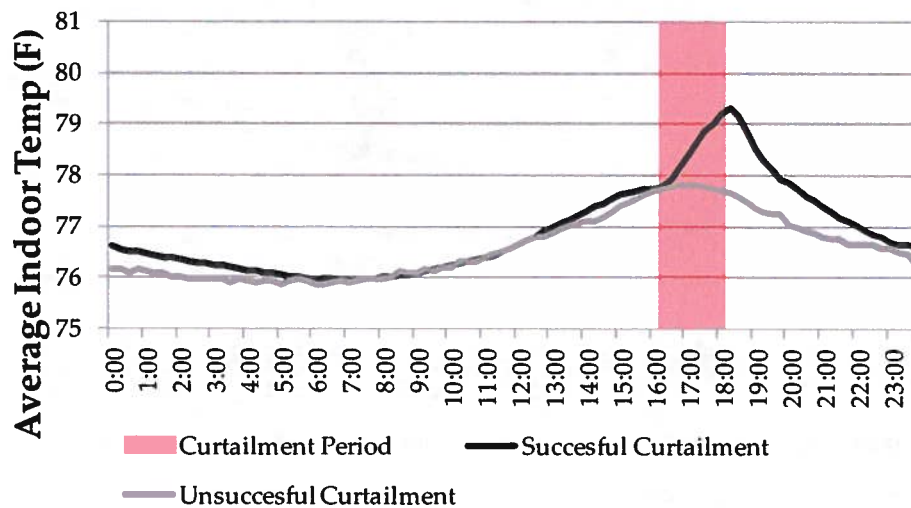
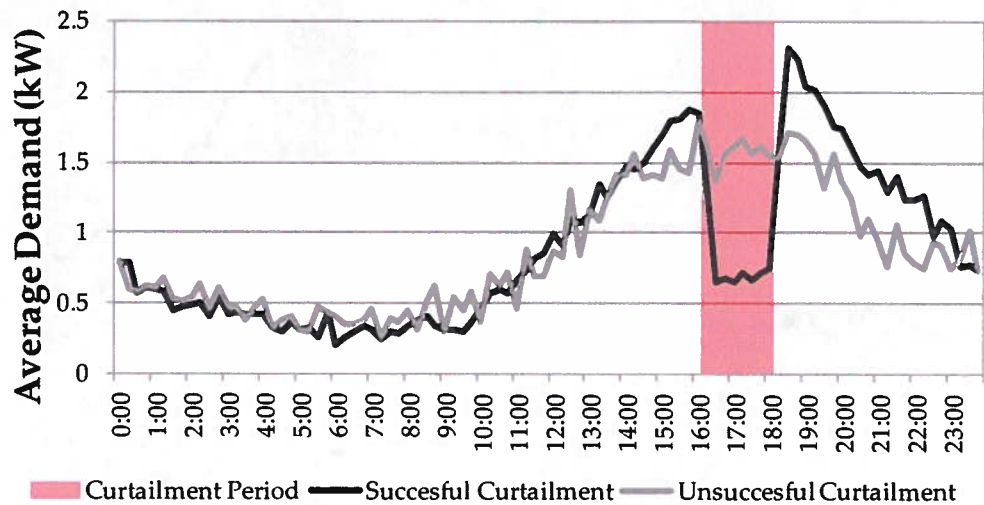
*Not shown in graph



Event C – 25% Threshold

Event Date	22-Jun-11	Curtailment Strategy	65%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	80	# Failed Curtail	19
# On During But Not Before Event*	6	# On During But Not After Event*	1
# Not On During Event*	13	Avg. Temp (F) At System Peak	95

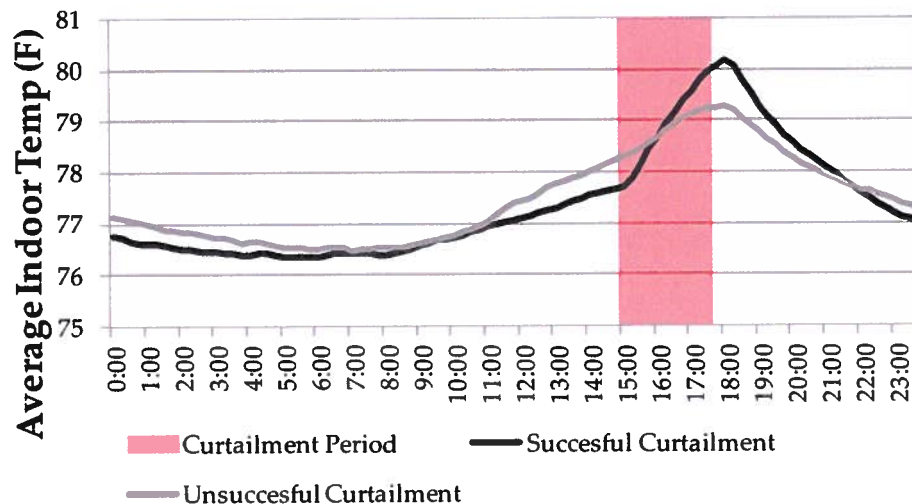
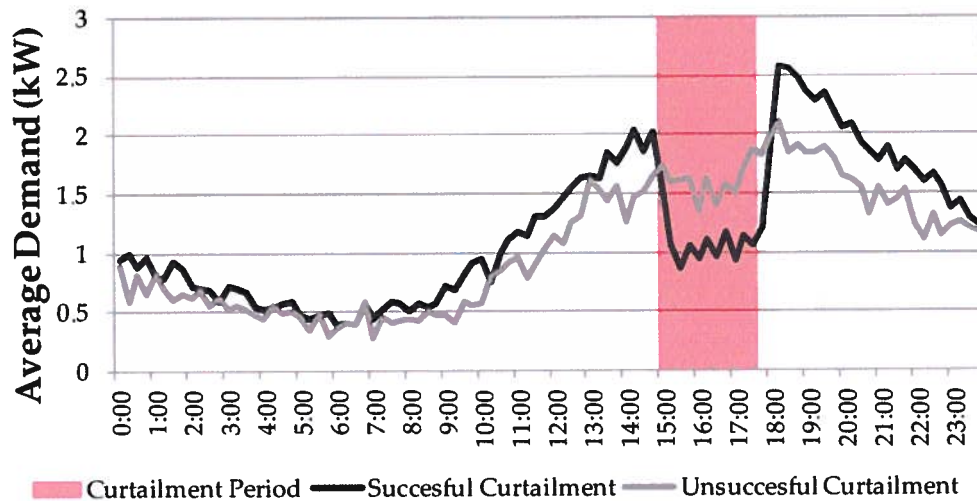
*Not shown in graph



Event D – 25% Threshold

Event Date	12-Jul-11	Curtailment Strategy	50%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	73	# Failed Curtail	28
# On During But Not Before Event*	8	# On During But Not After Event*	0
# Not On During Event*	7	Avg. Temp (F) At System Peak	94

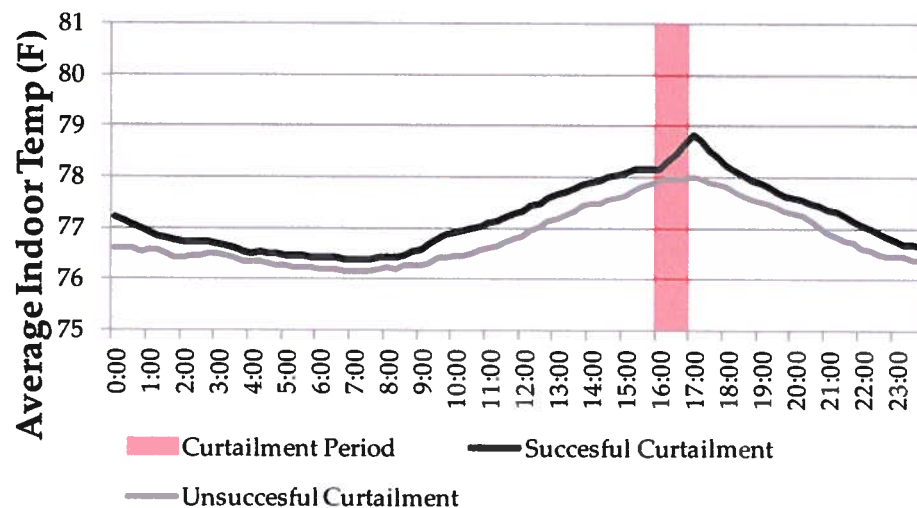
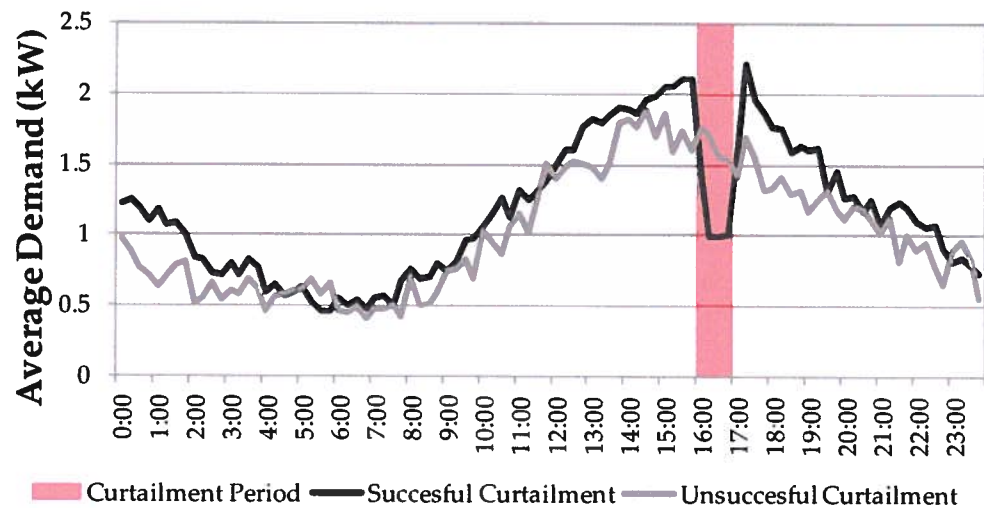
*Not shown in graph



Event E – 25% Threshold

Event Date	13-Jul-11	Curtailment Strategy	50%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	76	# Failed Curtail	25
# On During But Not Before Event*	0	# On During But Not After Event*	2
# Not On During Event*	8	Avg. Temp (F) At System Peak	98

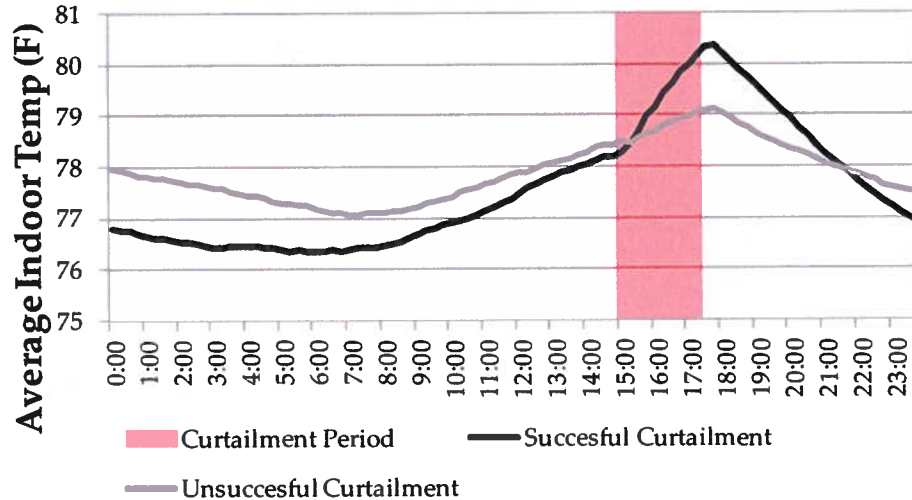
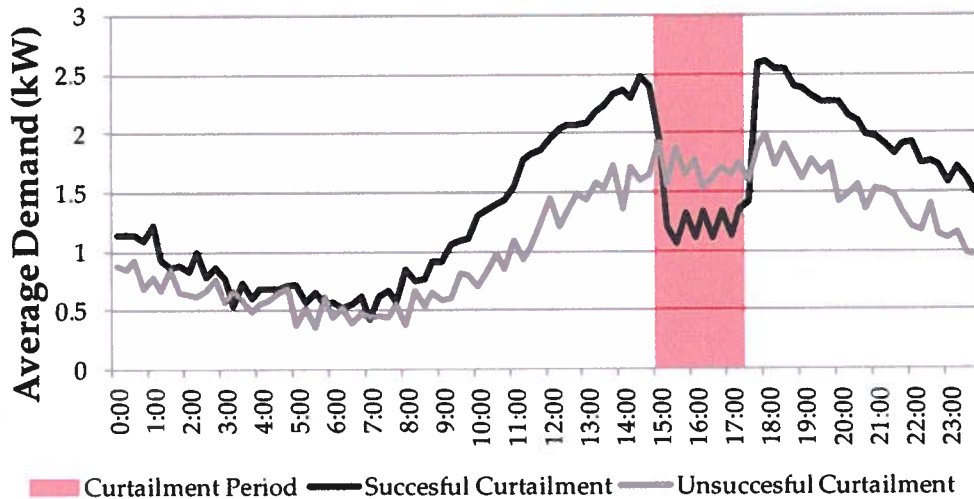
*Not shown in graph



Event F – 25% Threshold

Event Date	22-Jul-11	Curtailment Strategy	50%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	73	# Failed Curtail	22
# On During But Not Before Event*	5	# On During But Not After Event*	1
# Not On During Event*	11	Avg. Temp (F) At System Peak	95

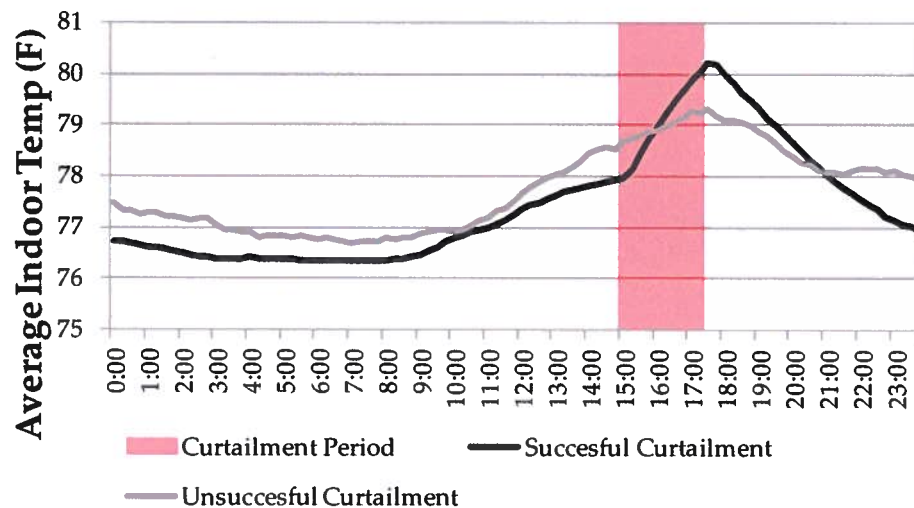
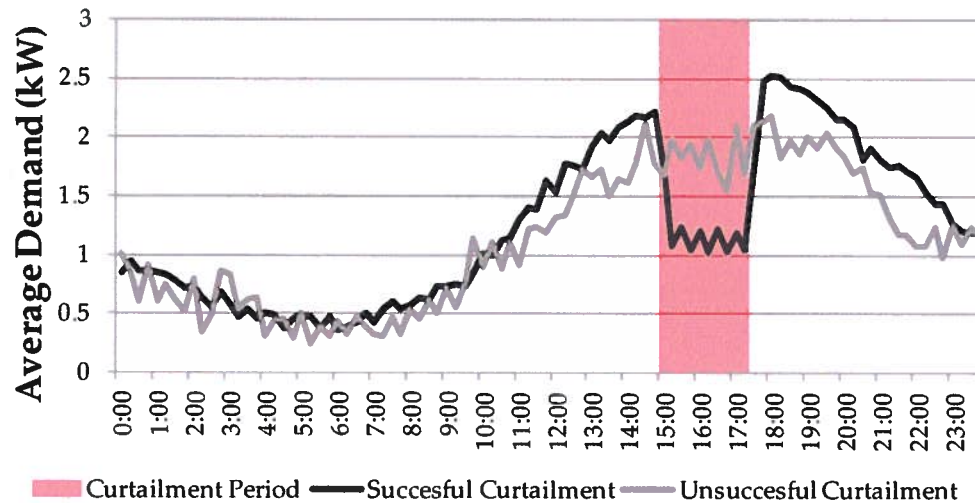
*Not shown in graph



Event G – 25% Threshold

Event Date	29-Jul-11	Curtailment Strategy	50%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	81	# Failed Curtail	18
# On During But Not Before Event*	6	# On During But Not After Event*	0
# Not On During Event*	7	Avg. Temp (F) At System Peak	100

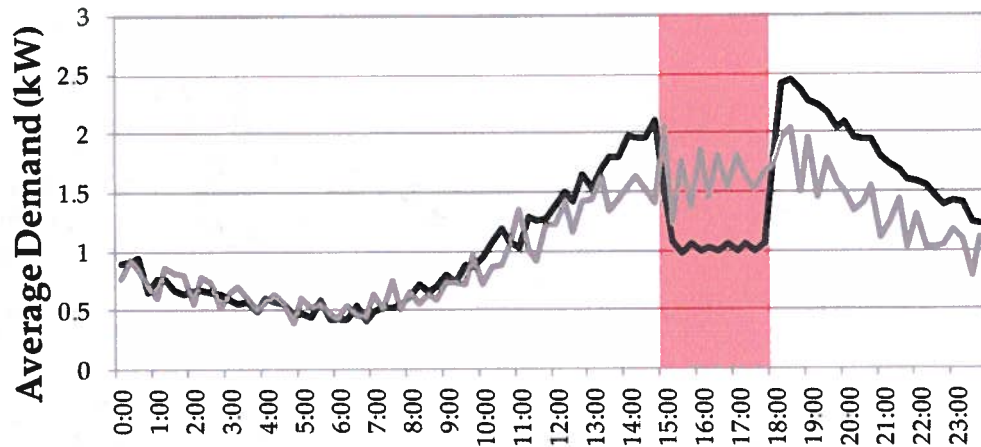
*Not shown in graph



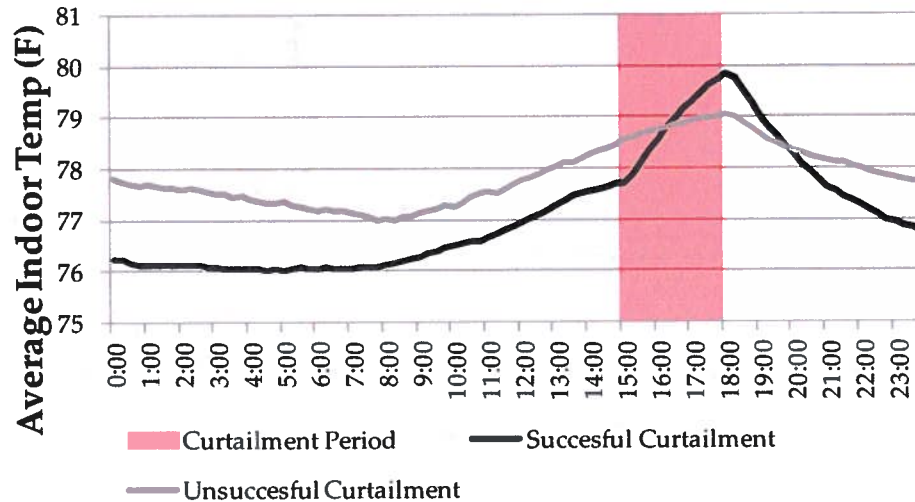
Event H – 25% Threshold

Event Date	4-Aug-11	Curtailment Strategy	50%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	74	# Failed Curtail	25
# On During But Not Before Event*	3	# On During But Not After Event*	2
# Not On During Event*	6	Avg. Temp (F) At System Peak	100

*Not shown in graph



█ Curtailment Period — Successful Curtailment — Unsuccessful Curtailment

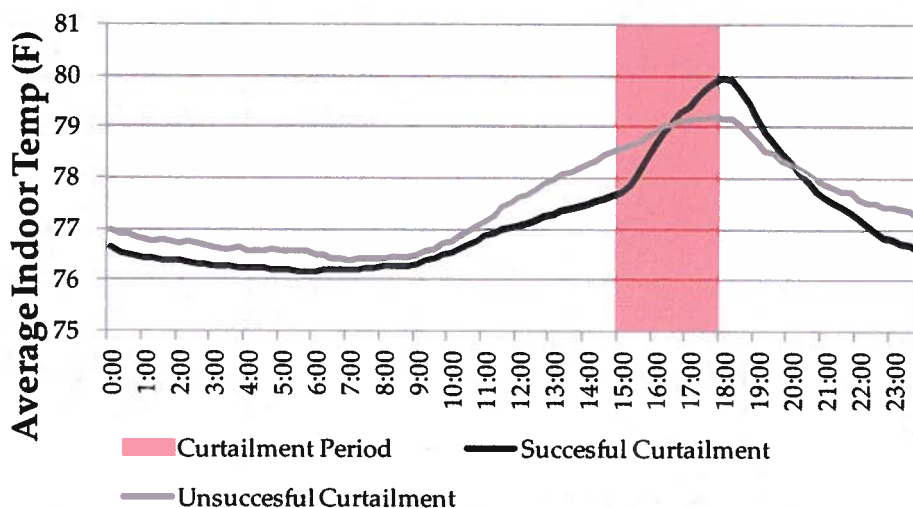
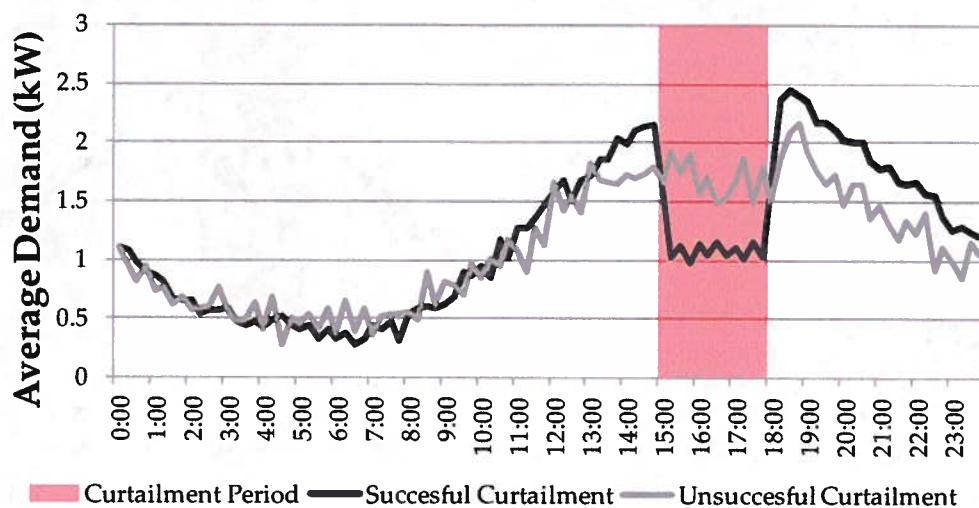


█ Curtailment Period — Successful Curtailment — Unsuccessful Curtailment

Event I – 25% Threshold

Event Date	8-Aug-11	Curtailment Strategy	50%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	63	# Failed Curtail	25
# On During But Not Before Event*	10	# On During But Not After Event*	4
# Not On During Event*	6	Avg. Temp (F) At System Peak	95

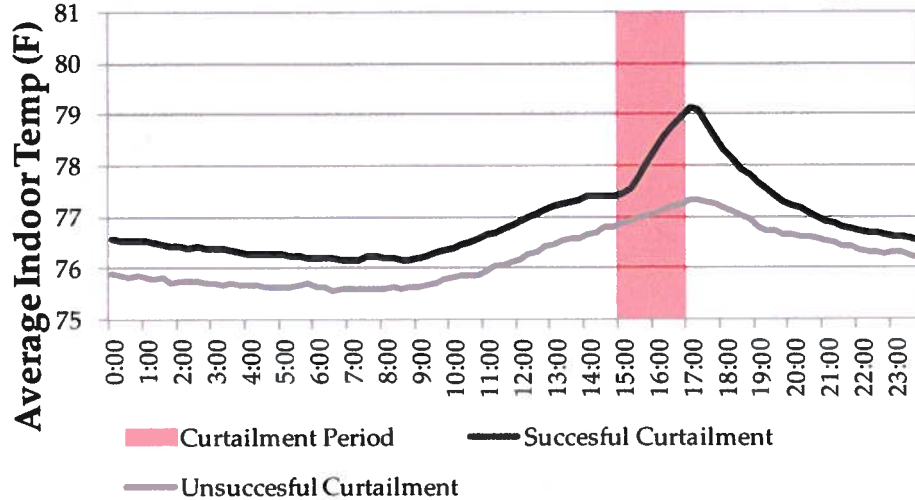
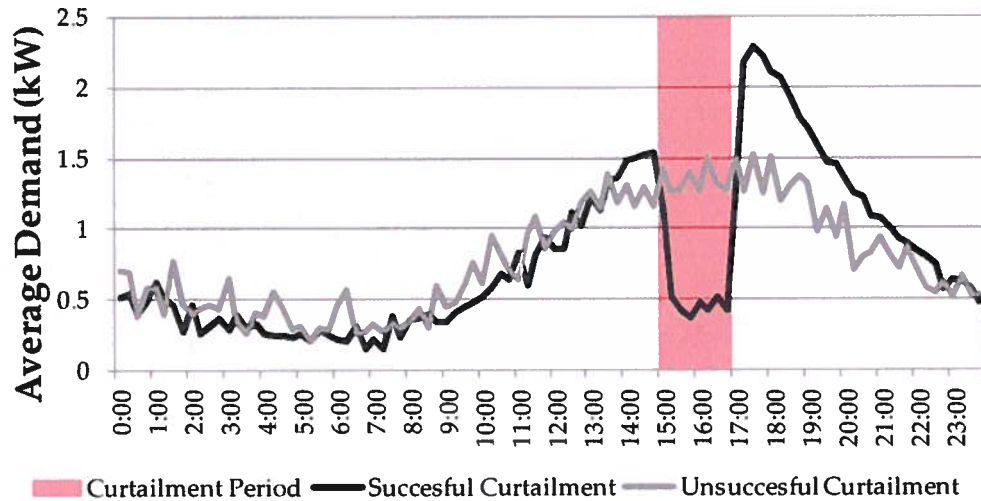
*Not shown in graph



Event J – 25% Threshold

Event Date	22-Aug-11	Curtailment Strategy	75%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	66	# Failed Curtail	19
# On During But Not Before Event*	11	# On During But Not After Event*	2
# Not On During Event*	10	Avg. Temp (F) At System Peak	96

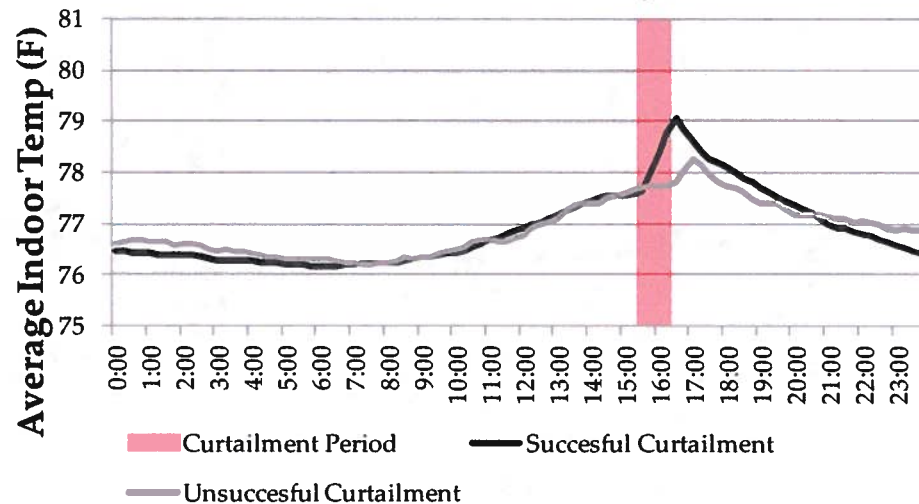
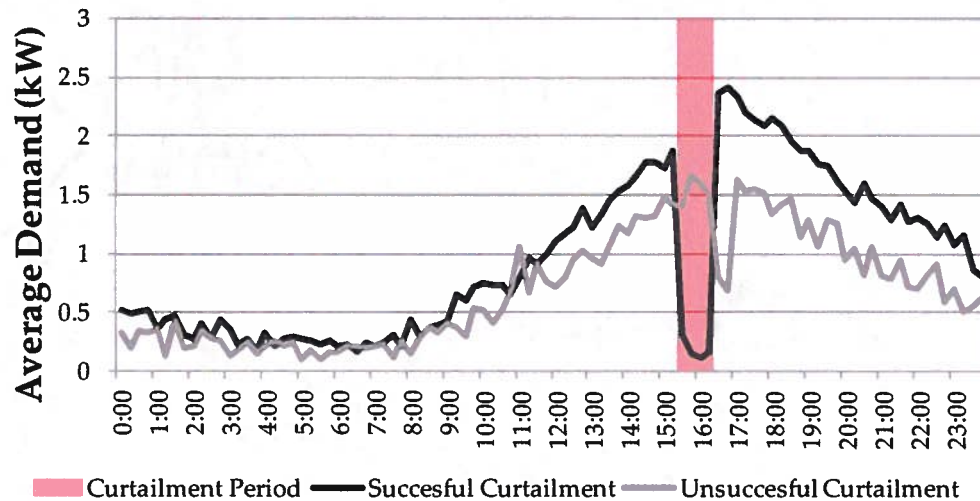
*Not shown in graph



Event K – 25% Threshold

Event Date	25-Aug-11	Curtailment Strategy	100%
Threshold	25%	Comparator Period	Prior Hour
# Successful Curtail	67	# Failed Curtail	21
# On During But Not Before Event*	7	# On During But Not After Event*	1
# Not On During Event*	12	Avg. Temp (F) At System Peak	90

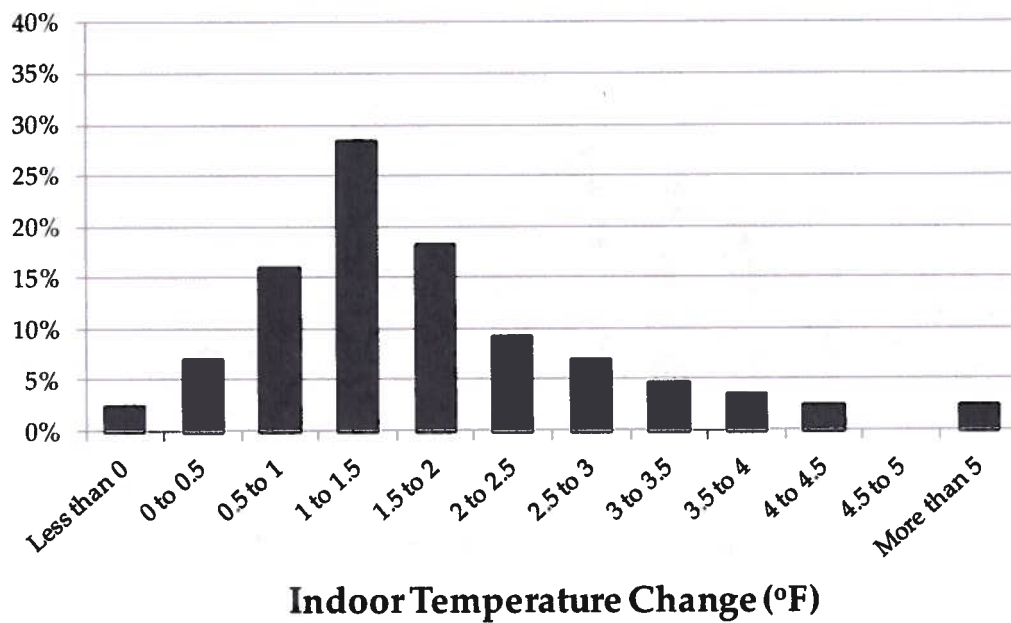
*Not shown in graph



Appendix J. Summer Temperature Histograms and Plots

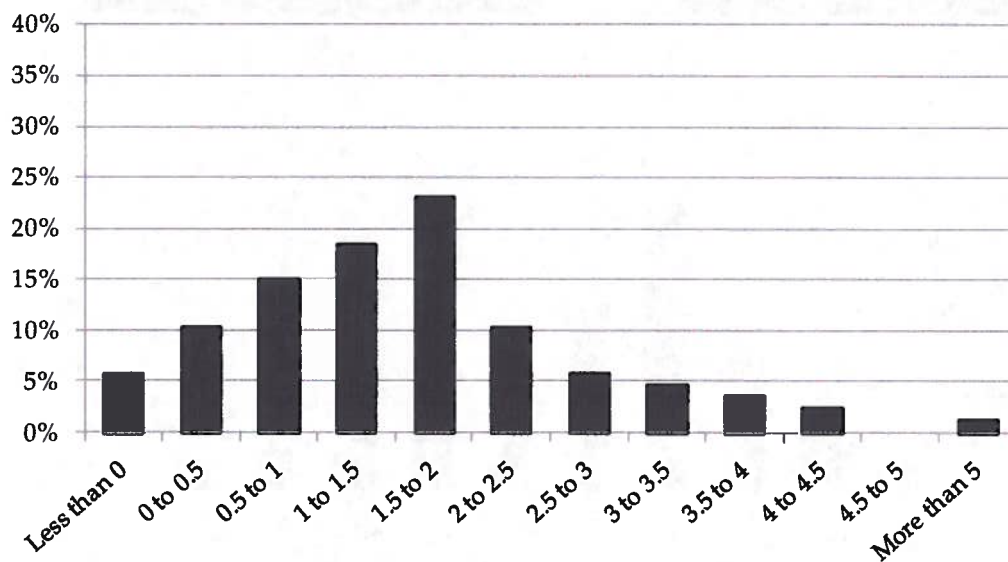
Event A

Event Date	1-Jun-11	Curtailment Strategy	50%
Avg. Temp (F) During Event	91	Length of Event (Hours)	2.0



Event B

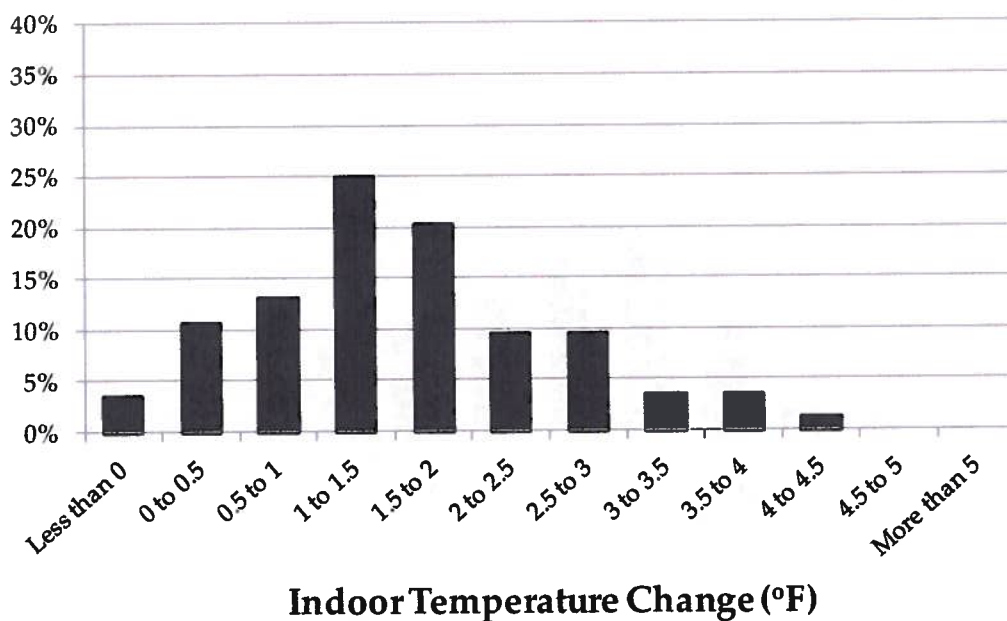
Event Date	9-Jun-11	Curtailment Strategy	50%
Avg. Temp (F) During Event	90	Length of Event (Hours)	2.0



Indoor Temperature Change (°F)

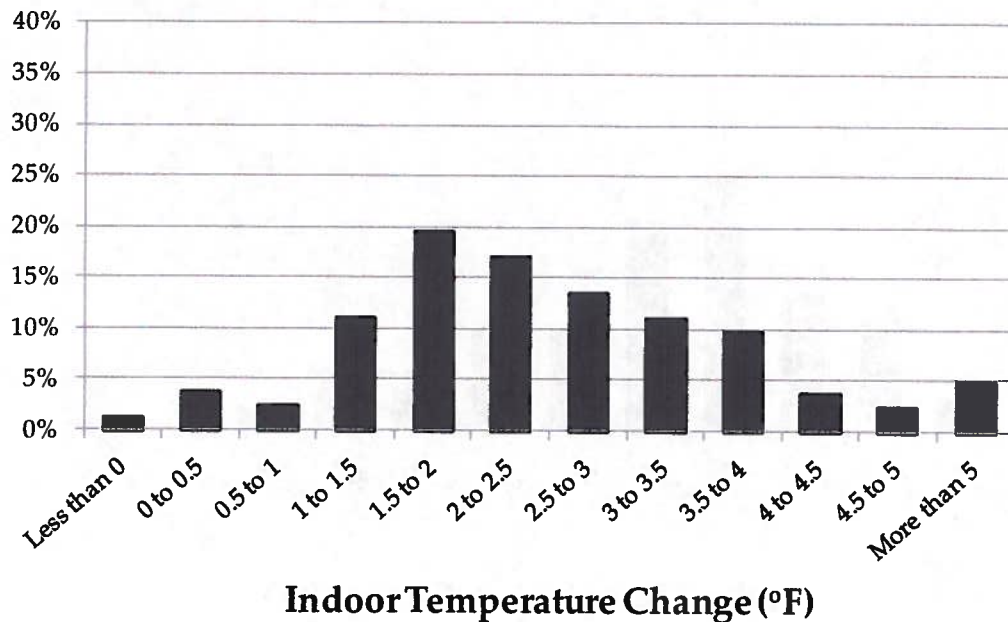
Event C

Event Date	22-Jun-11	Curtailment Strategy	65%
Avg. Temp (F) During Event	90	Length of Event (Hours)	2.0



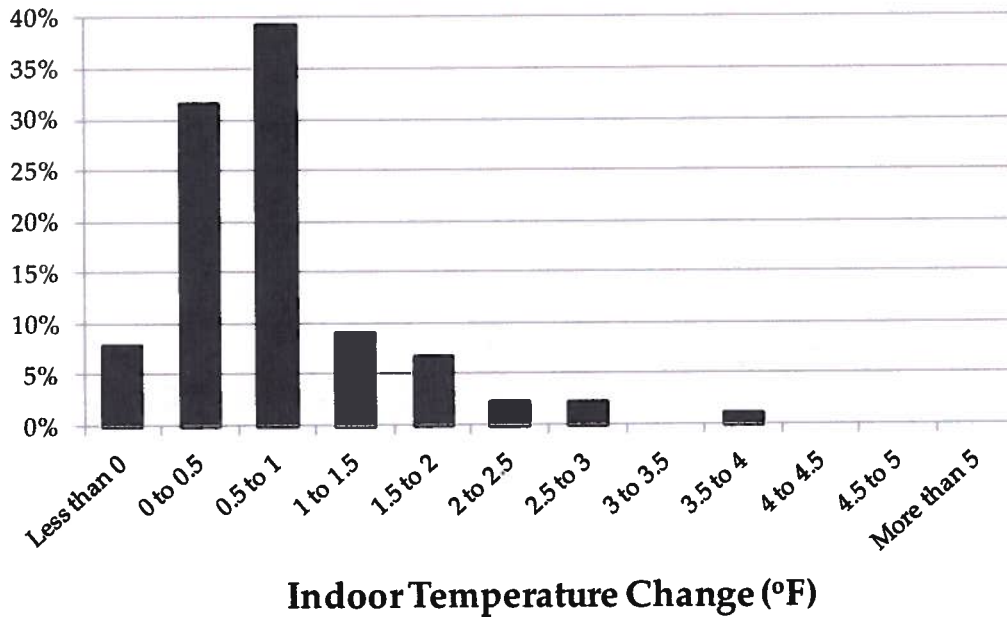
Event D

Event Date	12-Jul-11	Curtailment Strategy	50%
Avg. Temp (F) During Event	96	Length of Event (Hours)	3.0



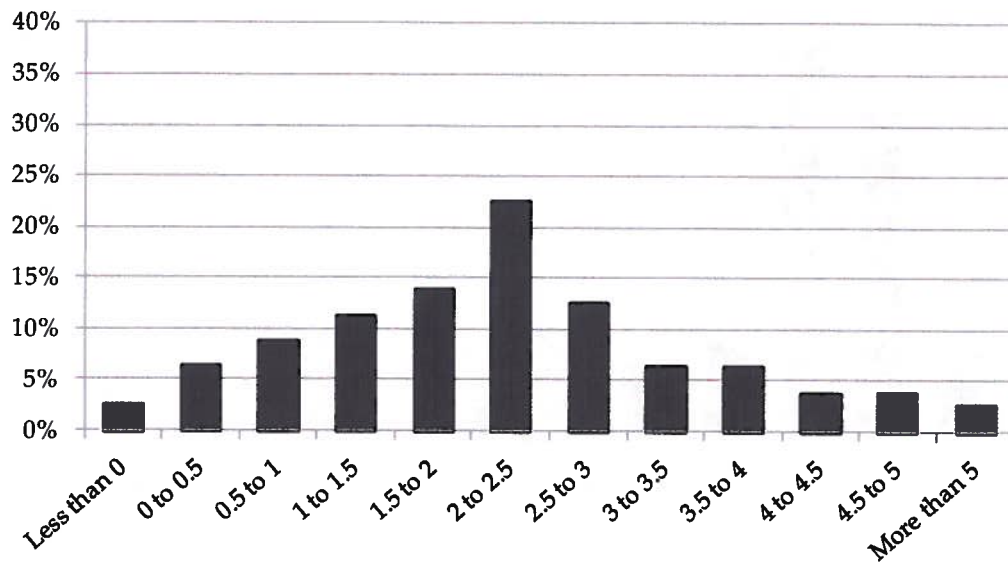
Event E

Event Date	13-Jul-11	Curtailment Strategy	50%
Avg. Temp (F) During Event	89	Length of Event (Hours)	1.0



Event F

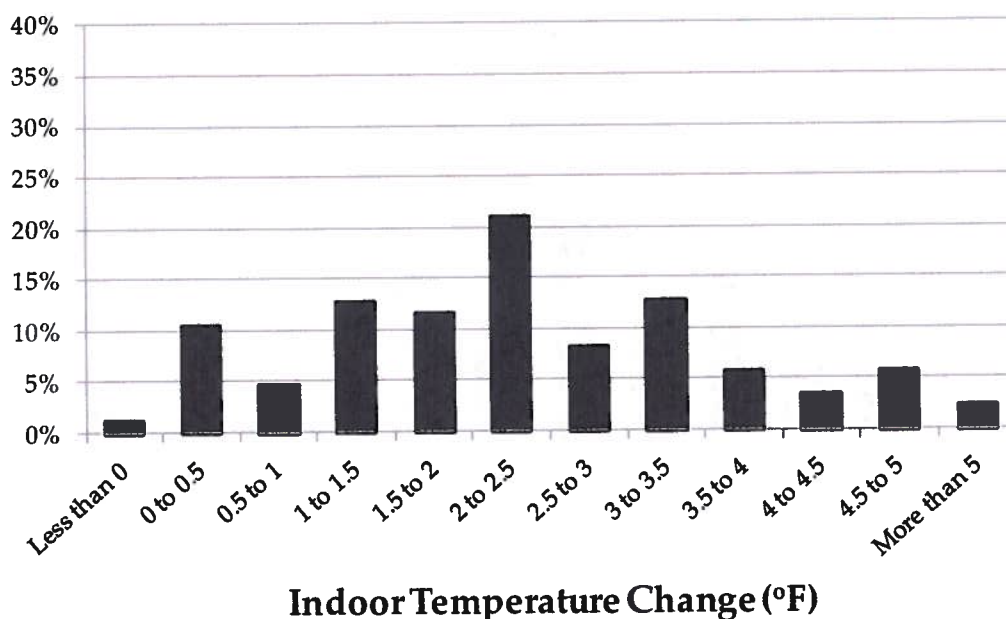
Event Date	22-Jul-11	Curtailment Strategy	50%
Avg. Temp (F) During Event	97	Length of Event (Hours)	2.5



Indoor Temperature Change (°F)

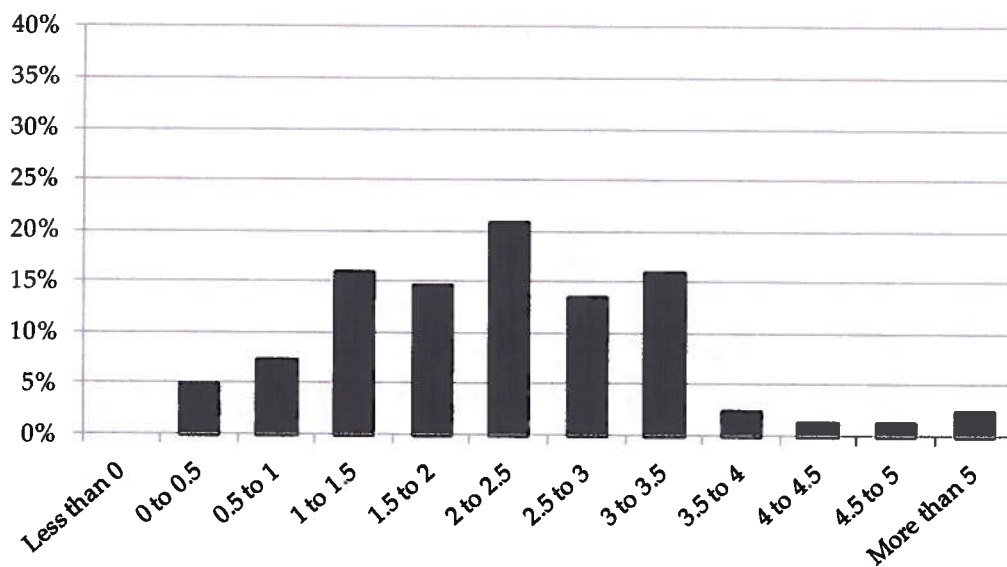
Event G

Event Date	29-Jul-11	Curtailment Strategy	50%
Avg. Temp (F) During Event	99	Length of Event (Hours)	2.5



Event H

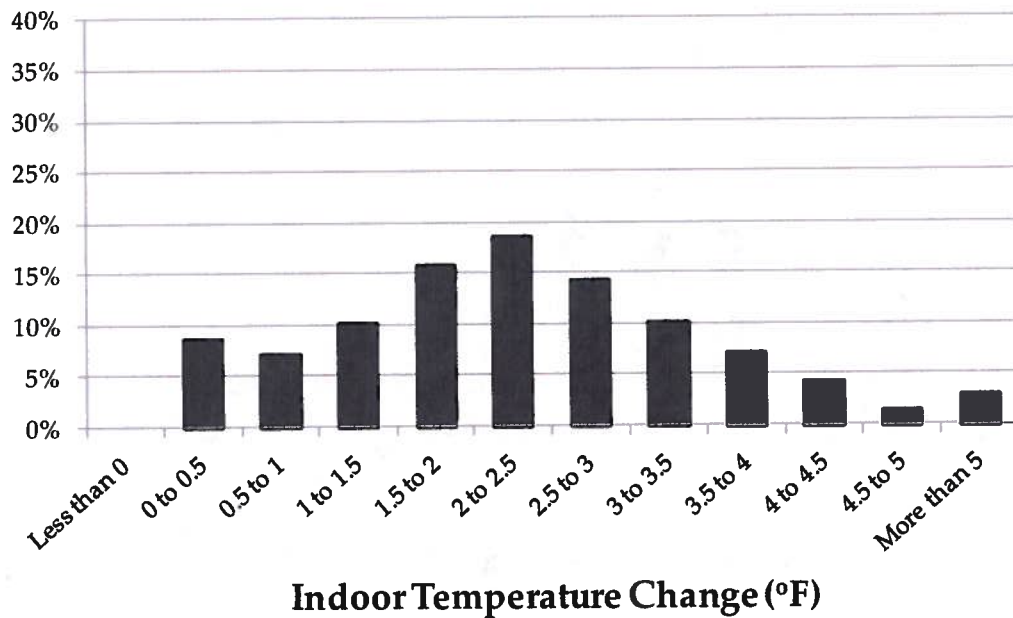
Event Date	4-Aug-11	Curtailment Strategy	50%
Avg. Temp (F) During Event	93	Length of Event (Hours)	3.0



Indoor Temperature Change (°F)

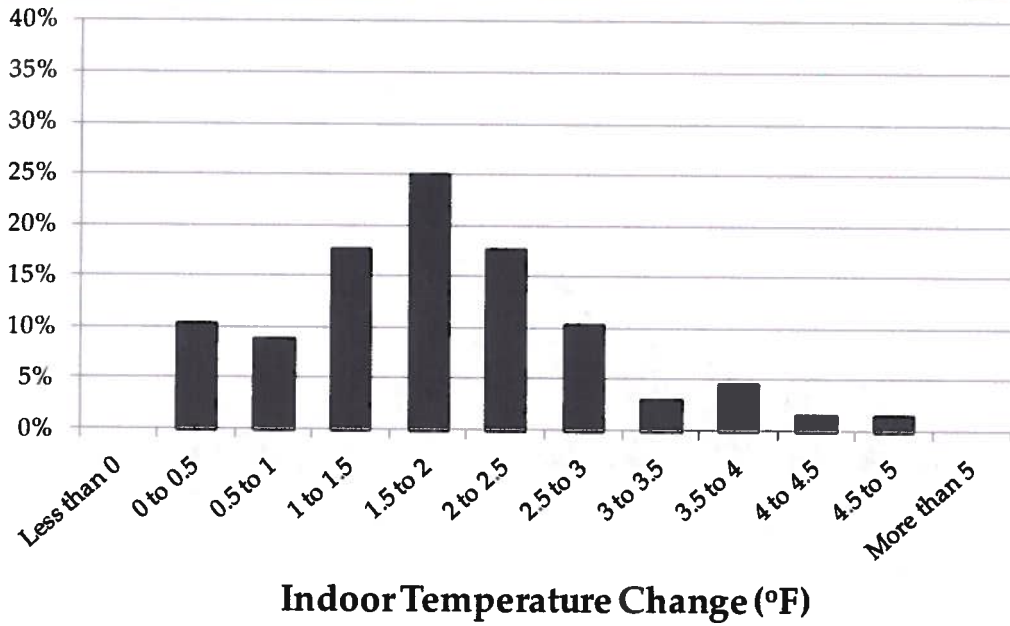
Event I

Event Date	8-Aug-11	Curtailment Strategy	50%
Avg. Temp (F) During Event	94	Length of Event (Hours)	3.0



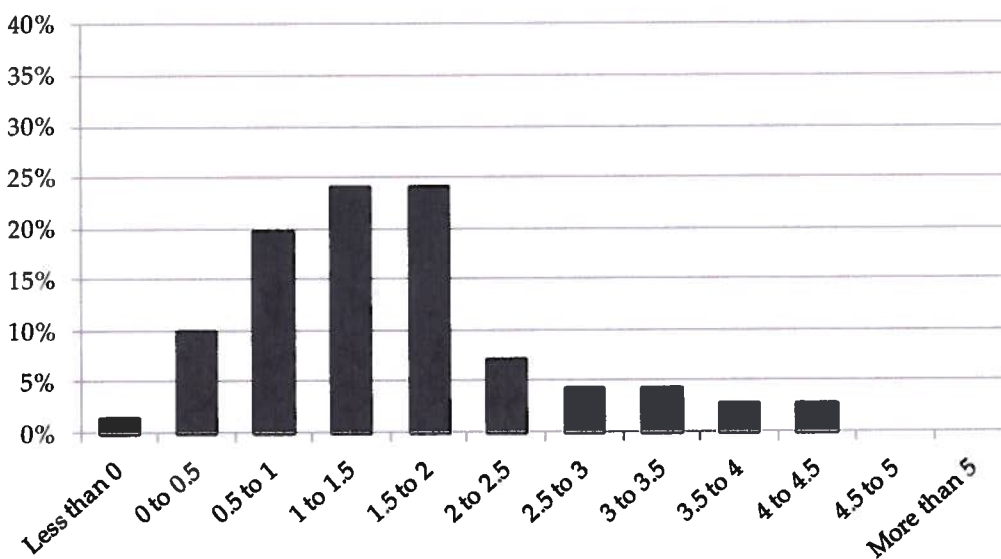
Event J

Event Date	22-Aug-11	Curtailment Strategy	75%
Avg. Temp (F) During Event	87	Length of Event (Hours)	2.0



Event K

Event Date	25-Aug-11	Curtailment Strategy	100%
Avg. Temp (F) During Event	90	Length of Event (Hours)	1.0



Indoor Temperature Change (°F)

